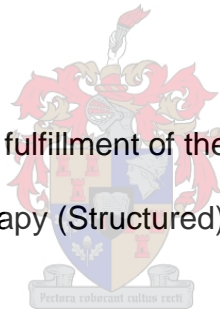


# Hip and Pelvis Kinematics during a Stork Test in sports Participants with unilateral adductor related Groin Pain

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This thesis presented in partial fulfillment of the requirements for the degree of  
Master of Science in Physiotherapy (Structured) OMT at Stellenbosch University



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## Declaration Page

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

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# **Abstract**

## **Introduction**

Groin pain is one of the three most prevalent injuries obtained in sports such as soccer; Australian Rule football; Rugby Leagues and Ice Hockey. Research on the hip and pelvis biomechanics in adductor related groin pain in sport is scarce.

## **Objective**

The purpose of this study was to determine if there are any differences in the hip and pelvis kinematics during the ten seconds Stork Test in sports participants with unilateral groin pain compared to their healthy matched controls.

## **Methodology**

A descriptive study was conducted. Eighteen active sports participants were recruited from soccer and rugby clubs situated around the Cape Peninsula, Western Cape, South Africa. The three-dimensional (3D) hip and pelvis kinematics of nine cases with unilateral groin pain and ten healthy controls were analysed. Hip and pelvis kinematics were analysed in the CAF-3D Vicon Laboratory at Stellenbosch University, using an eight camera Vicon system. A positive adductor squeeze test was used as a diagnostic test during participant screening to include cases with unilateral groin pain. Each participant performed six ten second Stork Tests, three on the right and three on the left. The main outcome measures were 3D hip and pelvis kinematic from foot lift to foot contact, foot contact was defined as a moment during the movement when the vertical force on the plate exceeded a threshold of 30 N. Each of the unilateral groin pain cases were compared to their healthy matched controls.

Descriptive statistical techniques were used for all outcome measures; means and standard deviation (SD) was calculated, followed by a Student's t-test to determine significant

differences between the cases and controls. For all outcomes with p-values equal to or below 0.05, the effect size was calculated using the Cohen's D.

## Results

The findings of this study indicated a significant increase ( $p=0.03$ ) in the anterior/posterior pelvic tilt total range of motion of the unilateral groin pain cases in the sagittal plane compared to their matched healthy controls. Significantly increased ( $p=0.05$ ) internal/external rotation of the pelvis was noted in the transverse plane in unilateral groin pain cases compared to their healthy controls.

## Conclusion

Differences were found in the total range of motion in the pelvis between sports participants with unilateral adductor related groin pain and their matched controls. This may imply that the groin pain participants have a decreased ability to activate the stabilisers of the pelvis, adductors, abdominals and gluteus medius, in order to stabilise the pelvis during the movement. A possible reason for the decreased muscle control in the affected group can be decreased muscle strength or muscle inhibition due to pain. The findings may also imply that evaluation and rehabilitation of pelvis stability should be included in individuals suffering from groin pain. Future research should focus on exploring these muscular components during the Stork test, perhaps making use of EMG.

*Key words: groin pain', chronic groin pain', 'adductor related groin pain', 'evaluation', 'hip biomechanics', 'hip kinematics', 'pelvis biomechanics', 'pelvis kinematics', 'stork stance', 'stork test', 'hip kinesiology', 'pelvis kinesiology' 'physiotherapy evaluation', adductor strains', 'muscle control', 'soccer athletes', 'rugby players'.*

# Opsomming

## Inleiding

Lies pyn is een van die drie mees algemeenste beserings wat obgedoen word in sportsoorte soos sokker, Australieaanse Reëls Voetbal, Rugby en Ys Hokkie. Navorsing aangaande die heup en pelvis biomeganika in adduktor verwante lies pyn is sport is skaars.

## Doelwit

Die doel van hierdie studie was om te bepaal of daar verskille in heup en pelvis kinematika is tydens 'n tien sekonde oëievaar toets in unilateral lies pyn sport deelnemer vergelyk met hulle gesonde ooreenstemmende kontroles.

## Metode

'n Beskrywende studie is uitgevoer. Agtien aktiewe sport deelnemers was gewerf van sokker en rugby klubs gelee in die Kaapse Skiereiland, Wes-Kaap, Suid Afrika. Die drie demensionele (3D) kinematika van die heup en pelvis van nege gevalle met unilateral lies pyn en nege gesonde kontroles is ontleed. Heup en pelvis kinematika is ontleed in die CAF-3D Vicon Laboratorium by Stellenbosch Universiteit, met behulp van 'n agt kamera Vicon sisteem. A positiewe adduktor druk toets was gebruik as diagnostiese toets om deelnemers met unilateral lies pyn te werf. Elke deelnemer moes ses oëievaars toetse doen, drie links en drie regs. Die hoof uitkoms meting was die 3D heup en pelvis kinematika van voet lig tot voet kontak, voet kontak is beskryf as die oomblik gedurende die beweging wat die vertikale krag op die druk plaat 30 newton oorskry. Elk van die unilateral liespyn deelnemers is vergelyk met 'n gesonde ooreenstemmende kontrole.

Beskrywende statistiese tegnieke was gebruik vir berekeninge van alle uitkoms maatreels; gemiddeldes en standaardafwykings (SA), gevolg deur 'n Studente t-toets om beduidende

verskille tussen die gevalle en kontroles te bepaal. Vir al die uitkomstes met p-waardes gelyk of onder 0.05, is die effekgrootte bereken deur die Cohen's D

## **Resultate**

Die bevindinge van die studie dui op 'n beduidende toename ( $p=0.03$ ) in die anterior/posterior pelviese kanteling totale omvang van beweging by die unilaterale lies pyn deelnemers in vergelyking met hul ooreenstemmende kontroles. 'n Beduidende toename ( $p=0.05$ ) in die totale omvang van pelviese interne en eksterne rotasie is ook gevind in die unilaterale lies pyn deelnemers in vergelyking met hulle ooreenstemmende kontroles.

## **Gevolgtrekking**

Verskille was gevind in die totale omvang van beweging by die pelvis van sport deelnemers met unilaterale adduktor verwante lies pyn. Dit mag impliseer dat die lies pyn deelnemers 'n verminderde vermoë het om die stabiliseerders, adduktors, abdominale en gluteus medius, van die pelvis te aktiveer tydens beweging. A moontlike rede vir die verminderde spier beheer in die geaffekteerde groep kan verminderde spierkrag of spier inhibisie as gevolg van pyn wees. Die bevindinge mag ook impliseer dat evaluering en rehabilitasie van die pelvis stabiliteit in ag geneem moet word in individue wat met lies pyn sukkel. Toekomstige navorsing kan ook fokus op die spier aksie tydens die oefenings toets, met gebruikmaking van EMG tegnologie.

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## Chapter 1: Introduction

Groin pain is one of the most common injuries amongst athletes taking part in sports that involve kicking, sprinting and sudden directional change (Serner 2015). It accounts for up to 16% of annual incidence of athletic injuries. Some of the sports that include this combination of movements are soccer, rugby, football, ice hockey as well as field hockey. (Tyler et al, 2010; Morrissey 2012; Sedaghati et al, 2013; Sheen 2014; Branci et al, 2015). According to a study done by Morrelli and Weaver (2005) up to 62% of groin injuries can be attributed to adductor related strains.

The typical mechanism of adductor related injury involves abduction and rotation on the hip joint, placing increased strain on the adductor muscle groups (Maffey & Emery, 2007). Strain of the adductor musculotendinous complex may lead to overuse injury of the adductor muscle group, resulting in the adductor muscle group being the most prevalent cause of groin pain (Branci et al, 2015; Serner 2015; Sheen 2014; Morrissey 2012; Maffey & Emery, 2007).

Sheen (2014) stated that adductor related groin pain symptoms mostly originate at the common origin point of the rectus abdominis; adductor longus tendons and insertion of the inguinal ligament on the pubic bone. Hackney (2012) had a broader explanation of symptoms, including pain around the adductor muscles moving across the midline and inguinal region. The pain may spread laterally and proximally into the rectus muscle and distally into the perineum. Tenderness around the belly of the adductor longus may be present if associated spasms of the adductor muscles occur. The exact incident and onset of these symptoms are mostly unknown because of the athlete's persistence to play through minor injuries and not report the initial incident of the adductor muscle injury (Tyler et al, 2010).

In the adductor muscle group the adductor longus is most at risk for an overuse injury (Tyler et al, 2010). There are many risk factors that play a role in adductor related overuse injury. According to Maffey & Emery (2007) non-modifiable risk factors include previous injury of the adductor muscles, sports experience, age, sport specific pre-season training, body mass index (BMI) and decreased diameter of the dominant leg femur. Mosler et al (2015) identified past injury and decreased adductor strength as two of the biggest risk factors for adductor related groin injuries with a reduced hip range of motion showing conflicting evidence as a risk factor. Sedaghati et al (2013) regarded some of the most common risk factors to be decreased flexibility of the adductor tendons, decreased adduction-to-abduction strength ratio and a history of previous injury. A study done in 1983 showed a decreased hip range of motion in pre-season training resulted in more frequent groin sprains (Sedaghati et al, 2013). Morrissey (2012) also found the balance between hip abductors and adductors play an important role due to their reciprocal actions and the frequency of myotendinous adductor pathology associated with these multidirectional sports. Therefore overuse injuries may result from altered motor control strategies for load transfer between the pelvis and the lower limbs. During single leg stance activities the hip abductor muscle must produce a force twice that of the body weight to create a stable pelvis in the frontal plane (Neumann 2010).

A good contraction of the hip and pelvis musculature during single leg weight bearing is therefore of vital importance in creating a more stable base for better load transfer between from the upper body to the lower limbs preventing a lateral hip drop/ Trendelenburg pattern. The main abductors and adductors required to create this co-contraction is the gluteus medius and adductor longus muscles (Morrissey 2012). It is important for the hip to create a stable biomechanical structure, during single leg stance, creating a stable force and load distribution to the lower limb to prevent injury-altered motor control strategies that may lead to increased incidence of groin injury (Morrissey 2012). Therefore research was done in previous studies (Mosler et al, 2015) with regard to hip and pelvis kinematics and muscle pattern activation during a single leg stance.

The normal biomechanical function of the pelvis and stability during weight transfer can be greatly influenced by the soft tissue surrounding the structure. The assessment of pelvic motor control during activities where a force or load is transferred across the pelvic articulation is therefore relevant (Hungerford et al, 2007). Screening of athletes for variances in gait, posture and flexibility at the hip and pelvis are of vital importance to prevent the onset or recurrent injuries. Important areas of assessment in outpatient settings are the mobility of the hip joint, adductor squeeze Test, posterior pelvic tilt test and gluteus control (Sheen 2014). The Trendelenburg Sign is commonly tested in research and clinical practice during the standing hip flexion test (Stork Test). Altered muscle pattern activation may lead to changes in the lumbopelvic and femoropelvic movement patterns. This altered pattern may lead to a reduction in the abduction to adduction muscle activation, resulting in altered pelvic tilts; translation may lead to overuse injury (Hungerford et al, 2007; Neumann 2010).

The purpose of this study was to explore the three-dimensional (3D) kinematics of the hip and pelvis in three planes during a Stork stance in sports participants with chronic adductor related groin pain compared to healthy subjects. The specific objectives were to compare:

1. Pelvis Peak and Minimum angles of unilateral groin pain sport's in participants to their healthy matched controls in the frontal, sagittal and transverse planes during the Stork test. The movement of the pelvis was measured from foot lift to foot contact. Foot contact was defined as a moment during the movement when the vertical force on the plate exceeded a threshold of 30 Newton (N).
2. Hip Peak and Minimum angles of unilateral groin pain in sports participants to their healthy matched controls in the frontal, sagittal and transverse planes during the Stork test. The movement of the hip was measured from foot lift to foot contact. Foot contact was defined as a moment during the movement when the vertical force on the plate exceeded a threshold of 30 N

3. Total range of motion of the hip and pelvis in unilateral groin pain in sports participants to their healthy matched controls in the frontal, sagittal and transverse planes during the Stork test. The movement of the Pelvis and hip measured from foot lift to foot contact. Foot contact was defined as a moment during the movement when the vertical force on the plate exceeded a threshold of 30 N.

The hypothesis of this study is that kinematic differences will exist between unilateral chronic groin pain sports participants, cases, and their healthy matched controls.

## Chapter 2: Literature review

### Aim of the review

The aim of this review was to provide insight into the kinematic changes associated with the Hip and Pelvis due to adductor related groin pain among unilateral groin pain sports participants compared to their matched control.

This review will also aim to define groin pain, the biomechanics of the hip and pelvis and the changes associated with groin pain as well as the possible kinematic risks that could influence normal function of the of the hip and pelvis during sports participation.

The following Stellenbosch University electronic databases were searched: *Pubmed*, *Science direct*, *Cochrane*, *Pedro* and *Cinahl*. Google Scholar and 'The Journal of Biomechanics' was also searched to source appropriate articles. Keywords used during these searches, in different combinations, included '*groin pain*', '*chronic groin pain*', '*adductor related groin pain*', '*evaluation*', '*hip biomechanics*', '*hip kinematics*', '*pelvis biomechanics*', '*pelvis kinematics*', '*stork stance*', '*stork test*', '*hip kinesiology*', '*pelvis kinesiology*', '*physiotherapy evaluation*', '*adductor strains*', '*muscle control*', '*soccer athletes*' and '*rugby players*'.

The literature search was conducted from September 2014 to September 2015.

This current study forms part of a research being conducted at Stellenbosch University. A broader search on the Biomechanical changes in Groin pain sports participants is being done. The bigger study focuses on all joint Biomechanics and movement affected by Groin pain. This research has started a few years ago and was also part of research done in 2014 by the previous OMT Structured Masters group. In my study I only researched a small part of the bigger topic, focussing on the hip and Pelvis during a Stork Test, only to give more insight to a small amount of data in the bigger research.

## Definition of groin pain

Adductor related groin pain can be defined by the following criteria (Machotka et al, 2009):

- Subjective information from the athlete that pain arises from the area of ilioas, adductor muscle group or lower abdominal musculature.
- Pain on palpation of the adductors or lower abdominal musculature, pubic symphysis or pubic bone.
- Positive adductor muscle length or strength test
- Pain in the above mentioned area causes reduced function or athletic activity .

According to Mens et al (2006) groin pain related to adductor tendinitis specifically, causes pain near the attachment on the pubic bone, and pain can be provoked by isometric hip adduction and palpation of the adductor tendon. Groin pain could be attributed to a few different diagnoses, besides adductor tendinitis, such as osteoarthritis of the hip, inguinal hernia, as well as a few less defined possibilities like bulging of the abdominal wall, entrapment neuropathy or abdominal wall muscle tendinopathy.

## Prevalence of groin injuries

According to Brachi et al (2015), 12 to 16% of annual sports injuries are accounted for by groin injuries with adductor related groin injuries being the most common. Groin pain is one of the three most prevalent injuries obtained in sports such as soccer, Australian Rule football, Rugby Leagues and Ice Hockey (Mosler et al, 2015). Less commonly affected sports are swimming and cycling owing to the reduced pelvic and torso movements that are known to increase the chances of groin injuries (Sheen 2014).

Serner et al (2015) stated that groin injuries, be it acute or longstanding, are frequent in sports involving rapid directional change. Owing to the high incidence of longstanding symptoms as well as the high recurrence of groin injuries it represents a major problem for these sport participants due to substantial absence from their sporting activities.



Due to the high incidence of longstanding symptoms as well as the high recurrence of groin injuries it represents a major problem for these sport participants. In male, sub-elite soccer players groin injuries are some of the most common injuries, these injuries are followed by iliopsoas related and abdominal related injuries (Holmich et al, 2014).

## **Kinesiology of the Pelvis and Hip**

As explained in Neumann (2010), the hip is a multi-axial ball-and socket joint that balances the upper body during normal movement. The ability of the hip joint to support the forces from the upper body relies on the stability of the joint. The forces acting on the joint are experienced at the femero-acetabular articulation, compressing the hip joint. With these compressive forces the need arises to balance the moment arms of the body's weight, causing a pull from the hip abductors to maintain a level pelvis. The muscular forces generated for pelvis stability are the primary contributions to the joints' reactive forces during gait and standing, with body weight only contributing a lesser force (Neumann 2010).

When discussing the muscle action and kinesiology that take place around the hip, it can be organized according to 3 main planes of motion. These include the sagittal, transverse and frontal plane. In each of these planes a muscle's action is in the orientation of its line of force, relative to the joint's axis of rotation.

Movement in the sagittal plane results in an anterior/posterior tilting of the Pelvis and a flexion or extension movement at the hips. During any single leg, weight bearing activities, the initial muscle contraction creates more stability at the pelvis than the femur. If the pelvis is not stabilised by the surrounding muscle the strong force of the hip flexor muscles, mostly a force created by rectus abdominis, anteriorly tilts the pelvis. Therefore a person with weak abdominal muscles may not be able to create sufficient force to counter the strong anterior pull of the hip flexors resulting in an increased, uncontrolled anterior tilt of the pelvis on the femur. During rapid flexion of the hip, the flexion is generally preceded by the activation of

the abdominal muscles, most dramatically seen at the transverse abdominis, especially in subjects with no lower back pain. This is seen as a feed forward mechanism designed to increase the stability of the lumbo pelvic region (Neumann2010).

In the transverse plane most of the short external rotators of the hip have a near-horizontal line of force. This overall line of force creates a near perpendicular intersection with the hips' longitudinal axis of rotation. Therefore, external rotation is produced by almost all the given muscle which is aligned to create a compressive force in the hip joint, providing a mechanical stability to its articulation. As the hip flexion significantly increases the piriformis, posterior fibres of the gluteus minimus and anterior fibres of the gluteus maximus start to reverse the rotary action and internally rotate the hip. This dramatically increases when the hip is flexed to 90° (Neumann2010).

In the frontal plane the hip abductors play an important role in stabilising the pelvis during the swing phase of gait and during all single-limb supporting activities. During these activities the gravitational adduction torque around the hip increases drastically as soon as the contra lateral limb leaves the ground. The abductors must then respond to the increased torque by created a counted abduction force to stabilize the pelvis during the activity. During single leg stance activities the moment arm of the hip abductor muscle groups are about half of the moment arm used by the bodies weight. The hip abductors muscle must produce a force twice that of the body weight, with the difference in moment arm lengths, to create a stable pelvis in the frontal plane (Neumann 2010).

In all the mentioned planes of movement there is an almost constant demand on the adductor muscle group through all the hip and pelvis range of motion which may partially explain their relatively high susceptibility to overuse injury (Neumann2010). Many of the adductor muscles are bilaterally and simultaneously active to increase pelvic controls during sports that involve rapid and complex movements (Neumann2010). With athletic activities

the magnitude of forces increase, placing their orientations at the end of the articulation limits, causing extra requirements from the joints surrounding muscles, ligaments and cartilaginous structures in order to assist the load transfer in the joint. Any alterations in the anatomy of the hip through any injury or degeneration can significantly affect the normal function and ranges of the hip, causing a decreased ability of the hip for load transfer and pelvis stability (Bowman et al, 2010).

## **Hip & Pelvis muscle dysfunction**

Excessive strain and overuse of the adductor muscle group can cause changes to the hip and Pelvis stability, changes in motor control, and may lead to injury of the adductor muscle group (Morrisey 2012). There is some evidence available that shows that the muscle pattern activation surrounding the hip and pelvis changes in patients with groin pain (Mosler et al, 2015). Muscle pattern activation at the hip and pelvis is vital for stability during functional and athletic movement. Balance between hip abductors and adductors are important owing to their reciprocal action and the high incidence of myotendinous adductor pathology associated with certain athletic movements (Morrisey et al, 2012). Muscle around the hip and pelvis affected by pathology can cause a significant disruption to the fluidity and comfort of both functional and recreational activities. Abnormal performance of affected musculature also affects the distribution of forces across the joints articular surfaces, leading to degenerative changes in the cartilage, bone and surrounding structures (Neumann 2010).

Based on muscle orientation and line of force in the sagittal plane the femur rotates toward the pelvis or the pelvis toward the femur if a sufficiently strong enough contraction is isolated from the hip flexor muscles. Surrounding muscles stabilise the pelvis during contraction of

the hip flexors if this stability is impaired an increased anterior tilt of the pelvis will take place. One of the muscle groups that counter the pull of the hip flexors are the abdominals, creating a posterior pelvic tilt. If these abdominal muscles are weakened, an undesired an excessive anterior tilt of the pelvis will take place (Neumann 2010).

During a study of chronic groin pain compared to a controls group, the subjects were asked to do an active straight leg task. During the active straight leg raise, electromyography activity of the transverse abdominis, obliquus internus, externus and rectus femoris were measured. In the group with groin pain, compared to the control group, the onset of transverse abdominis relative to rectus femoris was delayed. None of the other muscles tested had a significant different onset time relative to rectus femoris (Mosler et al, 2015). In the same study by Mosler et al (2015) the transverse abdominis was significantly thinner at rest, as well as during the active straight leg raise. Leading to a weakened as well as delayed transverse abdominis function.

In the frontal plane, contraction of the hip abductors and adductors create a stable pelvis for weight and load transfer (Neumann 2010). The adductor muscle group has a high susceptibility for overuse injury because of the almost constant biomechanical demand on the muscle group through a wide range of hip positions and movements (Neumann 2010). Morrissey (2012) also found that the balance between hip abductors and adductors play an important role due to their reciprocal actions and the frequency of myotendinous adductor pathology associated with multidirectional sports. They had the thought that these overstrain injuries result from this altered motor control strategies for load transfer between the pelvis and the lower limbs.

For single leg weight bearing it is of vital importance for the hip musculature to have a good contraction in the frontal plane, creating stability at the hip and pelvis and preventing a lateral

hip drop or Trendelenburg pattern. The main abductors and adductors required to create this co-contraction is the gluteus medius and adductor longus muscles (Morrisey 2012).

Morrisey (2012) found significant muscle activation ratio differences in the Gluteus medius (GM) vs Adductor longus muscle activity in an athlete with groin pain during the stance phase compared to a matched control. This difference was primarily due to the GM activation, with test subjects having a marked reduction in activation levels at all stages in the hip flexion movement. During an MRI study adductor longus tendinopathy (increased signal intensity of MRI, seen as thickening of the tendon) was visible in 72% of symptomatic and 71% of asymptomatic soccer players, this may suggest that micro tears or soccer-related overuse irrespective of current symptoms may lead to chronic structural changes in the adductor longus tendons of these athletes (Branchi et al, 2015).

In the transverse plane the gluteus maximus is one of the major external rotators of the hip, with no primary internal rotators. There are a few secondary internal rotators, including the anterior fibres of gluteus medius, Tensor fascia lata, Adductor longus and Brevis, Pectineus and posterior head of adductor magnus. In a single leg stance a strong contraction from the gluteus medius would therefore create effective extension and external rotation force. Although data does indicate that if the hip is significantly flexed, the gluteus maximus along with other short external rotators, reverse their action and become internal rotators. If the hip and pelvis have decreased stability, or altered muscle pattern activation, the typically flexed position of the hip would exaggerate the internal rotation of the hip and pelvis (Neumann 2010)

### **Biomechanical Risk factors**

A systematic review by Mosler et al (2015) identified previous history of injury, as well as decreased adductor strength risk factors for adductor related strains. Mosler et al (2015) also indicated that there is conflicting evidence regarding reduced hip range of motion is a risk factor. Prevention programmes aimed at reducing the incidence of groin pain have had little

effect, even though they are aimed at addressing potentially modifiable risk factors as mentioned above, the incidence and recurrence rate of groin injuries still remain high.

Groin injuries have a high incidence of longstanding or chronic symptoms, causing a major concern and the recurrence rate of these symptoms are also high. Previous injury to the groin had a significant increase in the risk of re-injury, with the injury mostly reported on the same side as the previous incident (Holmich et al, 2014). Factors that could not predict an increased risk of groin injury included the athletes playing position and previous ankle, knee or lower extremity muscle injury (Holmich et al, 2014).

With soccer being one of the sports with the highest incidence of groin injury risk factors need to be researched and prevented. Soccer typically acts as a strengthening activity for the hip abductors but this does not seem to be present for the eccentric training of the hip adductors, resulting in a limited ability of the adductors to adapt to these high repetitive loads. Soccer is at the same time a kinking and directional changing sport, placing increased stress on the adductors creating an increased risk for being injured. A higher incidence for groin injury on the dominant side (68%) could also relate to this, with the adductor longus being most at risk of injury during the movement from hip extension to hip flexion due to high eccentric load that is put on the kicking leg during the swing phase (Holmich et al, 2014).

Sedaghati et al. (2013) also found that a history of sprains to the groin and decreased range of motion were seen as risk factors for groin injuries. During their research they found players with frequent groin injuries had limited hip range of motion, preseason. Players with weakness of their adductors or a decreased adductor to abductor ratio had a higher incidence of groin injuries.

## Physical evaluation of groin injuries

In the last decade pelvic girdle function testing has moved away from Sacro-iliac joint mobility testing and more towards functional assessment procedures, focussing on testing the ability of the pelvis to maintain a stable position during load transfer between the spine and the lower limbs (Hungerford et al, 2007). This shift in testing procedures has started due to the increased understanding of the pelvis and the role it plays during load transfer. The normal biomechanical function of the pelvis and stability during weight transfer can be greatly influenced by the soft tissue surrounding the structure. The assessment of pelvic stability during activities that create load transfer across the pelvic articulation is therefore important.

The Stork Test is such one of these load transfer activity. During the Stork Test the Posterior Superior Iliac Spine (PSIS) is palpated with the one hand with the innominate bone of the side that will be taking weight, while the other hand palpates the sacrum centrally on the second sacral bone (S2). The direction of bone motion, the lack thereof or an increased pelvic motion is then palpated as the contra lateral foot is lifted off the ground (Hungerford et al. 2007). During the Stork Test stability of the pelvis is of vital importance, a decreased ability of the pelvis to maintain its position would lead to a positive sign, Trendelenburg Sign, or a negative sign if the test subject is able to maintain the hip and pelvis angles throughout the movement. The Trendelenburg Sign is commonly tested during the standing hip flexion test (Stork Test) or other more subtle movement abnormalities of the pelvis or hip area contraction of the abductors and adductors are of vital importance during single leg weight bearing, of these muscles the gluteus medius (GM) and adductor longus (AL) are the most significant and accessible during EMG studies. EMG activation rations, comparing GM: AL between the injured leg during stance and non-injured subjects' stance of the standing hip flexion test shows a significantly lower ration in the injured subjects at the onset and middle phase of movement. The injured subject's also show a markedly lower activation ratio between the injured moving leg and the non-injured subjects moving leg of the standing hip

flexion test. With analysis, the underlying reason shows AL with a slightly higher activation across all time points (Morrisey 2012).

Altered muscle pattern activation may lead to changes in the lumbopelvic and femoropelvic movement patterns. This altered pattern may lead to a reduction in the abduction to adduction muscle pattern activation, resulting in altered pelvic tilts or translation and a Trendelenburg Sign. In symptomatic groin subjects altered coronal plane hip muscle pattern activation is present at the onset, middle and end of the hip flexion test movement, affecting both the moving leg and the stance leg (Morrisey 2012).

Screening of athletes for variances in gait, posture, stability and flexibility are of vital importance to prevent the onset or recurrence of injury. Important areas of assessment in an outpatient setting are the mobility of the hip joint, adductor squeeze test, posterior pelvic tilt test and gluteal control (Sheen 2014).

### **Management of biomechanical risk factors associated with groin pain**

According to Machotka et al (2009) one of the major problems with regards to the management of groin pain is that the exercises prescribed as part of the rehabilitation is largely without an evidence-based protocol, and mostly derived from the personal experience of the treating therapist. The rehabilitation is then mostly aimed at improving the stability of the hip and pelvis before surgical intervention is considered (Machotka et al, 2009).

In the same review studies were found that favourable outcome could be seen from exercise intervention (Machotka et al, 2009). This evidence supporting rehabilitative exercise to be the key component in the treatment of groin pain in athletes is few and no specific protocol or specific exercise intensity noted. Strengthening exercise of the hip and abdominal



muscles is mostly supported by the available evidence (Machotka et al, 2009). Looking at the biomechanical risk factors, decrease muscle function of the abdominal muscles creates an increased anterior tilt of the pelvis in the sagittal plane (Neumann 2010). This would support strengthening of these muscles as stated. These strengthening exercises need to be progressed from static to functional positions and performed through the whole range of motion.

According to Serner et al (2015) exercise must be the major treatment component in the treatment of groin pain, although the evidence is poor. One of the biggest aims during the treatment of any elite athlete is to minimise the total time away from sports and increase the player availability for the team. (Sheen 2014)

Branchi et al (2015) finds that short-term alleviation of groin pain symptoms is possible with a training programme aimed at improving the strength and coordination of adductor muscles. Almeida et al (2013) found at a 16 week follow up no significant difference between the multimodal treatment and exercise therapy for successful treatment and full return to sport. Some injuries result in longer rehabilitation times and may become chronic. These long-standing groin pain injuries may be resistant to treatment and result in slow recovery times (Serner et al, 2015).

The findings of a systematic review by Serner et al (2015) revealed that 75% of the studies reported on surgical interventions while the rest reported on conservative treatment. . Conservative treatment consisted of passive physical therapy modalities and/or exercise therapy or injection therapy. Surgical studies examined open hernia repairs, laparoscopic hernia repairs and adductor tenotomy. There was moderate evidence for active physical training (adductor and abdominal strengthening) being superior to passive physical therapy modalities for the treatment of chronic adductor related groin pain. For a quicker return to sport than just physical training, a multimodal treatment option with adductor warming,

stretching and a return to a running programme was found to be most successful (Sheen 2014).

As adductor related groin pain is the result of sporting or overuse activity, a period of rest is indicated. Improving internal and external rotation of the hip has also been proposed as a method of reducing the stress put on the groin and surrounding area. As the adductors of the hip play instrumental role in the stabilization of the pelvis during sporting activities, together with the gluteus, hamstrings and abdominal muscles. The possibility that improving control and strength of these muscles may improve the stability of the pelvis during functional activities, reducing the strain on the groin region (Almeida et al, 2013).

Almeida et al (2013) concluded: "It is important to note that, despite the limited evidence, the exercise therapy based on strengthening and co-ordination exercises appears to be more effective than a more passive treatment (stretching, electrotherapy and transverse friction massage). Strengthening abdominal and hip muscles seems reasonable because muscular imbalance may contribute to functional instability of the pelvis and the groin region."

## **Conclusion**

Up to 16% of injuries reported during sporting activities are related to the groin, with the adductor muscle group being the most prevalent cause of injury. Adductor related groin pain is reported mostly in sports with quick directional changes and high incidences of plyometric activities. To date and to the author's knowledge no studies have been conducted to link a change in the biomechanics of the hip during the Stork Test, or to show how these changes could be used to diagnose certain muscular dysfunctions in adductor related groin pain. The Stork test is typically used by physiotherapists to evaluate dysfunction pelvis as well as its surrounding muscle control. However the current literature shows a relation between the groin muscle function and the biomechanical changes of the hip and pelvis and its muscular stability. With specific focus during the Stork Test, the hip and pelvis musculature must

create a stable base for the movement, creating possible evaluation strategies to pin-point problem areas or structures in regards to adductor related groin pain. Intervention and rehabilitation of the correct muscle groups, focussing on strength training, correcting muscle imbalances and increase synergistic control have shown a reduction in adductor related groin injuries and re-injuries. Increasing our ability to evaluate a structure may lead to better diagnosis and treatment.

## **Chapter 3: The Manuscript**

**Manuscript to be submitted to Physical Therapy in Sport Journal**

*\*Journal guidelines included in Appendix A.*

# **Hip and Pelvis Kinematics during a ten second Stork Test in sports Participants with adductor related Groin Pain**

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## **Abstract**

### **Objectives**

To determine if there are any biomechanical differences at the hip and pelvis in sports participants with unilateral groin pain compared with their healthy asymptomatic controls.

### **Study design**

Descriptive, cross-sectional design.

### **Setting**

CAF-Motion Analysis Laboratory at Stellenbosch University, South Africa

### **Participants**

Eighteen subjects participated in the study. Nine asymptomatic controls and nine cases with groin pain were included. The cases were diagnosed with unilateral groin pain.

### **Main Outcomes**

Three-dimensional (3D) hip and pelvis kinematics were analysed from foot lift to foot contact during a ten second Stork test. The data was analysed in the Sagittal, Frontal and Transverse planes.

### **Results**

Cases with unilateral groin pain had significantly increase( $p=0.03$ ) total range of motion with pelvic anterior/posterior tilt compared to their matched healthy controls. Cases also had a significantly increased ( $p=0.5$ ) anterior/posterior rotation at the pelvis when compared to their matched controls.

## Conclusion

The findings in this study indicate that there are differences in the pelvis kinematics between sports participants with unilateral groin pain and their asymptomatic healthy controls. These findings imply that the pelvis and its stability should not be excluded when examining or treating sports participants or any individual with groin pain. Muscular control plays a big role in regards to stability at the pelvis during load transfer and recreational activities, future studies that include EMG testing are therefore warranted.

**Keywords:** *groin pain', chronic groin pain', 'adductor related groin pain', 'evaluation', 'hip biomechanics', 'hip kinematics', 'pelvis biomechanics', 'pelvis kinematics', 'stork stance', 'stork test', 'hip kinesiology', 'pelvis kinesiology' 'physiotherapy evaluation', adductor strains', 'muscle control', 'soccer athletes', 'rugby players*

## 1. Introduction

Groin pain is a common injury amongst athletes participating in sports that involve kicking, sprinting and sudden directional change (Serner et al, 2015). Groin injuries account for up to 16% of annual injuries in both soccer and Australian Rule football, with adductor muscle injuries being the most prevalent cause of groin pain (Branci et al, 2015; Serner et al, 2015; Sheen 2014; Morrissey 2012; Maffey & Emery. 2007). The typical mechanisms of adductor related groin injuries involve quick acceleration and sudden changes in direction. This causes combined abduction and rotation movement on the hip joint, placing undue strain on the hip structures, especially on the adductor muscle group (Maffey & Emery, 2007).

Overuse injuries to the adductor muscles are considered to be the main cause of groin pain (Serner et al, 2015). Symptoms of adductor related groin pain consists of pain around the adductor muscles, moving across the midline and inguinal region. Pain may spread laterally and proximally into the rectus muscle and distally into the perineum with tenderness around the belly of the adductor longus if associated spasms of the adductor muscles are present (Hackney 2012). Adductor longus muscle may be more susceptible than other adductor muscles to overuse strain injuries. This could be owing to its mechanical disadvantage with regards to the adduction of the thigh in open chain sporting activities (Tyler et al, 2010). These specific movements are required from sports like Australian Rule football and soccer, increasing stress and strain on the structures surrounding the hip leading to overuse of the adductor muscle group. Increasing the incidence of recurrent injuries and longstanding pain, results in increased time away from the game and reduced sports participation (Morrissey 2012; Holmich et al, 2014; Serner et al, 2015; Branci et al, 2015).

In these multidirectional sports the balance between hip abductors and adductors play an important role because of their reciprocal actions and the frequency of myotendinous adductor pathology (Morrissey 2012). An imbalance between the strength of these two



muscle groups forms a major risk factor for adductor related groin injuries (Almeida et al, 2013). There are many risk factors that play a role in adductor related overuse injury. According to Maffey & Emery (2007) non-modifiable risk factors include previous injury of the adductor muscles, sports experience, age, sport specific preseason training and body mass index (BMI). Mosler et al (2015) identified, in two systematic reviews, that past injury and decreased adductor strength were the two biggest risk factors for adductor related groin pain.

The muscle around the hip and pelvis plays an important part during functional and recreational activities, creating stability for force and load transfer from the upper body and pelvis to the lower limbs. Morrissey (2012) found that in the frontal plane during single leg weight bearing activities co-contraction of the abductors and adductors, with gluteus medius and adductor longus being the most significant muscles increase the motor control of the pelvis for lateral tilt. In the sagittal plane the hip muscles work together with the abdominal muscles to create a controlled anterior/posterior pelvic tilt during functional and sporting activity (Almeida et al, 2013). For single leg weight bearing it is of vital importance for the hip musculature to have a good contraction, creating stability and better load transfer between the pelvis and the lower limbs. Adductor related overstrain injuries may result in altered motor control strategies at the hip and pelvis during force and load transfer (Almeida et al, 2013). Altered muscle pattern activation may lead to changes in the lumbopelvic and femoropelvic movement patterns. This altered pattern may lead to a reduction in the abduction to adduction muscle pattern activation, resulting in altered pelvic tilts or translation (Hungerford et al. 2007).

The normal kinematics and stability of the hip and pelvis is greatly influenced by the muscles surrounding these joints during activities that require load transfer. The assessment of pelvic stability during activities that induce load transfer across the pelvic articulation is therefore important (Hungerford et al, 2007). Screening of athletes for variances in gait, posture and

flexibility may be of vital importance to prevent the onset and recurrence of injuries. Screening in an outpatient setting should typically include the mobility of the hip joint, Adductor Squeeze Test, and Pelvic Motor control tests (Sheen et al, 2015).

Pelvic control is often assessed during the standing hip flexion test (Stork Test) (Hungerford et al, 2007). A Trendelenburg Sign during the Stork test is observed when a reduction in the abduction to adduction muscle pattern activation is present, resulting in altered pelvic tilt or translation (Hungerford et al, 2007). Altered muscle pattern activation may lead to changes in the lumbopelvic and femeropelvic movement patterns. Hip and pelvis kinematics could therefore potentially be associated with groin pain, since the pelvis acts as a load transfer from the upper body to the lower limbs, and since the hip forms part of the lower limb working in the same kinematic chain as the injured hip. To date no studies have reported on pelvis and hip kinematic differences of unilateral groin pain sports participants when compared to their matched healthy controls during a Stork Test. Therefore, the aim of this study was to explore the 3D kinematic differences in the pelvis and hip of unilateral adductor related groin pain sports participants compared to their healthy controls.

## **2. Methodology:**

### **2.1 Objectives:**

- To compare the Pelvis Peak and Minimum angles of unilateral groin pain sports participants compared to their healthy matched controls in the frontal, sagittal and transverse planes during the Stork Test.
- To compare the Hip Peak and Minimum angles of unilateral groin pain sports participants compared to their healthy matched controls in the frontal, sagittal and transverse planes during the Stork Test.
- To compare the total Range of motion of the pelvis and hip in unilateral groin pain sports participants compared to their healthy matched controls in the frontal, sagittal and transverse planes during the Stork Test.

### **2.2 Ethical considerations**

Ethical approval was obtained from the Human Research Ethics Committee at Stellenbosch University. All participants completed and signed an informed consent form (Appendix C).

### **2.3 Study design**

A cross-sectional, descriptive study was conducted. The current study formed part of a larger study in which the biomechanical changes in several anatomical areas were examined, during the Stork Test. In this study only the data from the pelvis and hip joint during the Stork Test was analysed. Therefore the data in this study is very limited due to the restriction of only analysing the Hip and Pelvis Kinematics during the Stork Test, the data from all the other joints will be analysed by other members of the group, this will all be put together and form part of the bigger study.

## **2.4 Sample size calculation**

Using the G-Power Version 3.1 Statistical Power Analysis Program, a post hoc sample size calculation was made, considering a large effect of at least 1 (alpha 0.05) and sample size of 18 (which included 9 unilateral groin pain subjects and their controls). In the unilateral subgroup the power was calculated to be 97%.

## **2.5 Study location**

Data collection took place at the CAF-3D Motion Analysis Laboratory at the University of Stellenbosch Medical Campus. Screening of the participants was conducted at the relevant Sports club.

## **2.6 Study sample recruitment**

Participants were recruited by means of convenience sampling from appropriate rugby and soccer sports clubs situated in the Cape Peninsula area, Western Cape, South Africa. The physiotherapist and/or coach of each of the sports clubs were contacted via email explaining the aim and the procedure of the study (Appendix D). The physiotherapists or coaches were asked to identify potential participants, making sure they met the diagnostic inclusion criteria. Possible participants were screened for eligibility at the specified clubs. All eligible participants underwent a physical evaluation to exclude sacroiliac joint involvement or other instabilities that might be the cause of groin pain. Once a participant met all the inclusion criteria he was included in the study as a “case”. A matched control was recruited from the same club as the control. The case and control were matched by the sport they participated in, their respective weight and height. Once cases and controls were identified, possible dates and times for data collection were agreed upon. Prior to data collection a Pilot study was conducted in order to analyse the time it took to evaluate each participant as well as to stream line any difficulties that could arise during data collection.

### *2.6.1 Inclusion and exclusion criteria for cases*

#### **Inclusion Criteria**

- Soccer and rugby players at club level
- Males between the ages of 18-55 years
- Chronic unilateral or bilateral groin pain located at the proximal insertion of the adductor muscles on the pubic bone of any intensity, existing for a period longer than 3 months
- Groin pain during or after sporting activity
- Positive Adductor Squeeze Test with a sphygmomanometer (Delahunt et al, 2011)
- Participating in sport or physical training despite the groin injury
- Good general health

#### **Exclusion Criteria**

- Any orthopaedic surgical procedure of the lower quadrant and lumbar spine within the previous 12 months.
- Positive findings on previous imaging for bony lesions.
- Any disease that has an influence on functional ability/movement, e.g.: Ankylosing Spondylosis, Scheuerman's Disease, Rheumatoid Arthritis, Muscular Dystrophy and Paget's Disease
- History of spinal, lower limb or pelvis pathology other than groin injury.
- Symptoms of prostatitis or urinary tract infection

- Clinical suspicion of nerve entrapment syndrome
- Palpable inguinal or femoral hernia

#### *2.6.2 Inclusion and exclusion criteria for controls*

##### **Inclusion Criteria**

- Soccer & Rugby players at a club level
- Males between the ages of 18-55 years of age
- Males with no history of groin pain.
- Negative Adductor squeeze test with a sphygmomanometer (Delahunt et al 2011)
- Males participating in sport or do a form of physical training
- Only persons in good general health

##### **Exclusion Criteria**

- Any orthopaedic surgical procedure of the lower quadrant and lumbar spine within the past 12 months
- Any positive findings on previous imaging for bony lesions
- Any disease that has an influence on functional ability/ movement, e.g.:
  - Ankylosing Spondylitis
  - Scheuerman's disease
  - Rheumatoid Arthritis
  - Muscular Dystrophy and
  - Paget's disease
  - History of spinal, lower limb or pelvis pathology other than groin injury.

## **2.7 Instrumentation**

The Vicon Motion Analysis System (Ltd) (Oxford, UK) is a three dimensional (3D) system used in a wide variety of ergonomics and human factor applications. The system is capable of capturing 250 frames per second at full frame resolution (1 megapixel). For this study the

3D-kinematics of the pelvis and hip joint was assessed by an eight camera Vicon T-series Motion Analyses (Ltd) (Oxford, UK) system with Nexus 1.4 116 software to capture trials. The system was calibrated according to the manufacturers' settings prior to capture. The T-10 motion capturing system has a unique combination of high speed, accuracy and resolution. It is also considered the gold standard for movement analysis owing to its reliability and proven validity (Windolf et al, 2007).

## **2.8 Procedures**

All identified participants underwent a standardised screening assessment at their specific sports clubs. During the screening, a brief subjective interview was conducted where the inclusion and exclusion criteria were explained (Appendix E). This was followed by an objective examination (Appendix F) conducted by the researchers which included range of motion, height, weight and an Adductor Squeeze Test to ensure the groin pain was related to adductor related pathology.

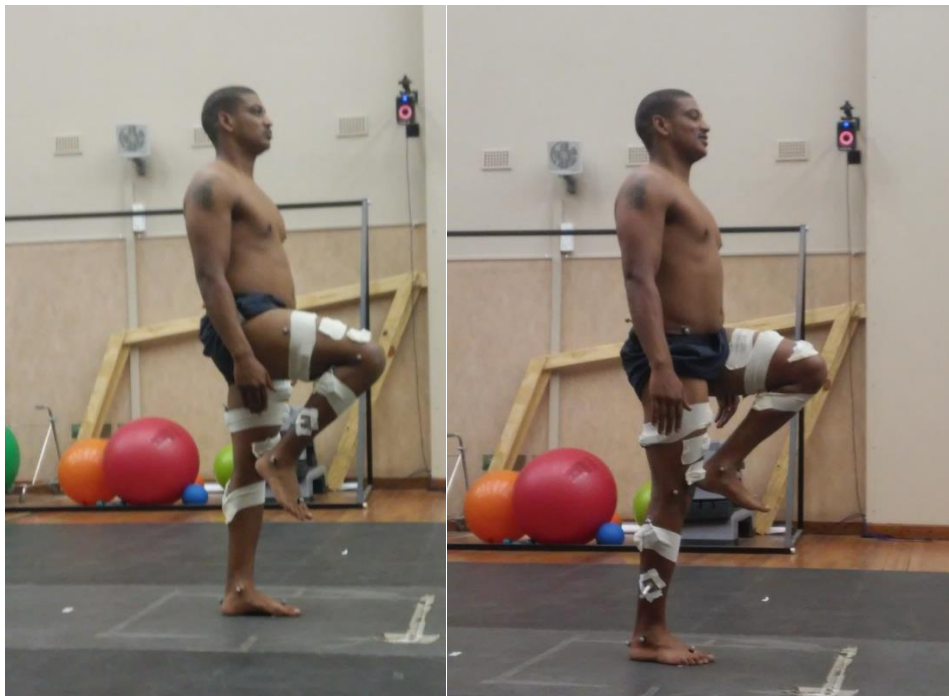
### **2.8.1 Pre-testing procedure**

Upon arrival at the CAF-3D Motion Analysis Laboratory at the University of Stellenbosch Medical Campus, participants' anthropometric measurements were taken for use by the Vicon System. These measurements included weight, height, leg length, knee width and ankle width. This was followed by lower limb range of motion measurements (hip; knee; ankle). After all measurements had been taken, motion analysis commenced. Participants were tested in shorts to appropriately expose relevant anatomical land marks for application of retro reflective markers. Nineteen retro reflective markers were placed on various landmarks (Appendix H).

### **2.8.2 Testing procedure**

Standardised warm-up of 5 minutes walking on the treadmill at a speed of 5.5 was completed by each subject prior to motion analysis.

Directly following the warm-up, participants were instructed to perform a Stork Test (Figure 1). The Stork Test requires a subject to stand with arms relaxed at their sides, with feet in a comfortable position. On instruction they then lift one leg to 90° hip and knee flexion and maintain this position for 10 seconds, keeping their eyes open. Measurements were taken from foot lift to foot contact. Foot contact was defined as a moment during the movement when the vertical force on the plate exceeded a threshold of 30 N. The test movement was first demonstrated and explained to the participants; thereafter the participant had a practise run on each leg. The test movement was repeated three times on each leg. Lowering the hip angle to below 45° or moving the foot was seen as a 'fail' and the test movement would then be repeated.



**Figure 1: Demonstration of Stork test**

## **2.9 Data processing**

Pelvis and Hip kinematics were measured in three respective planes: frontal, sagittal and transverse.

Possible gaps in the captured data were filled using the Standard Woltring Filter supplied by Vicon. The events for foot contact and lowest vertical position of the pelvis were calculated



automatically using Matlab Version R2012b. Segment and joint kinematics were calculated using the Plug-in-Gait Model and filtered with a 4th-order Butterworth Filter at a 10Hz cut-off frequency. Data was exported to Matlab to extract the parameters of interest.

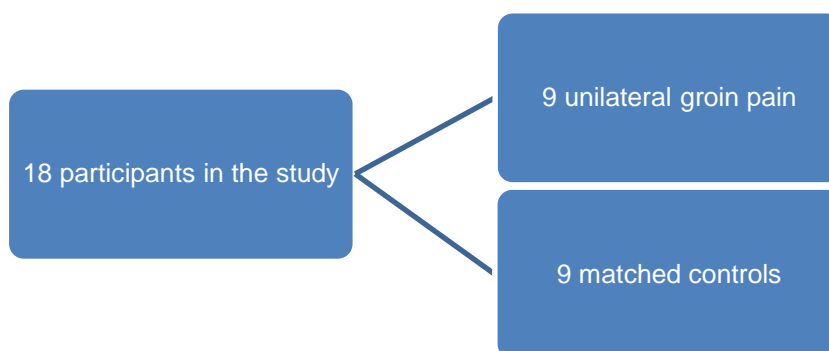
## 2.10 Data analysis

### 2.10.1 Kinematic Outcomes

The following kinematic outcomes were used to determine if there was a difference in the biomechanics of the pelvis and hip, observing the

- Peak and Minimum pelvis angles in the frontal, sagittal and transverse planes during the Stork test
- Peak and Minimum hip angles of the frontal, sagittal and transverse planes during the Stork test
- And the range of motion of the pelvis and hip in the frontal, sagittal and transverse planes during the Stork Test.

All the movements of the pelvis and hip were measured from foot lift to foot contact. Foot contact was defined as a moment during the movement when the vertical force on the plate exceeded a threshold of 30 N.



**Figure 2: Subgroups Division**

Descriptive statistical calculations (means and ranges to indicate variability) were used to describe the participant's demographics. All outcome measures (hip and pelvis kinematics) were calculated with these descriptive statistical techniques means and standard deviations (SD), followed by a Student's two-tailed t-test to determine the significant differences, if any between the cases and controls. A significant p-value equal to or less than 0.05 is used for all outcomes. The effect size was calculated using the Cohan's D to indicate the extent of the effect. The relative size of Cohan's D is illustrated below:

**Table 1: Cohan's D Values**

Effect	Size
Small effect	$\geq 0.15$ and $> 0.40$
Medium effect	$\geq 0.40$ and $0.75$
Large effect	$\geq 0.75$ and $1.10$
Very large effect	$\geq 1.10$ and $1.45$
Huge effect	$> 1.45$

### 3. Results

#### 3.1 Sample description

Eighteen participants (nine cases and nine controls) took part in this study. The anthropometric measurements of the participants (n=18) are represented in the table below. The ages of the cases that participated ranged from 19 to 38 years whereas the ages of the controls ranged from 21 – 28 years. There is a mean difference of 1.11 years between the two groups. There was also no significant difference in height and weight between the two groups. These anthropometric measurements were included for the mathematical model needed for the CAF-Vicon system.

**Table 2: Anthropometric measurements**

	Mean (SD) Age in yrs.	Mean (SD) Weight in kg	Mean (SD) Height in meters
<b>Pain Cases and Control n = 9</b>			
<b>Cases (n=9)</b>	24.78 (5.8)	85.01 (19.86)	1.78 (0.08)
<b>Controls (n=9)</b>	23.67 (3.0)	89.86 (18.41)	1.78 (0.09)

#### 3.2 Kinematic differences

##### 3.2.1 Pelvic Kinematics:

*Groin pain cases' injured side compared to the matching side of their controls*

##### 3.2.1.1 Pelvic Anterior/Posterior tilt

No significant differences were found in anterior and posterior pelvic tilt of the cases compared to their matched controls (p=0.2) (Table 3).

**Table 3: Pelvic anterior/posterior tilt Cases compared to matched controls**

	<b>Peak anterior pelvic tilt angles</b> Mean (SD)	<b>Peak posterior pelvic tilt angles</b> Mean (SD)	<b>Total Range of motion: Pelvic ant/post tilt</b> Mean (SD)
<b>Cases (n=9)</b>	12.7 ( $\pm$ 5.9)	1.3 ( $\pm$ 6.5)	11.4 ( $\pm$ 2.9)
<b>Controls (n=9)</b>	12.5 ( $\pm$ 6.0)	3.5 ( $\pm$ 4.2)	9.06 ( $\pm$ 4.3)
<b>p-Value</b>	p=1.0	p=0.4	p=0.2

**3.2.1.2 Pelvic Lateral Tilt**

There was also no significant difference in the lateral tilt of the pelvis, cases compared to matched controls (p=0.9) (Table 4).

**Table 4: Pelvic lateral tilt: Cases compared to Controls**

	<b>Peak upward lateral pelvic tilt angles</b> Mean (SD)	<b>Peak downward lateral pelvic tilt angles</b> Mean (SD)	<b>Total Range of motion: lateral pelvic tilt</b> Mean (SD)
<b>Cases (n=9)</b>	-1.1 ( $\pm$ 3.5)	-12.1 ( $\pm$ 3.2)	11.0 ( $\pm$ 3.0)
<b>Controls (n=9)</b>	-0.9 ( $\pm$ 4.0)	-12.2 ( $\pm$ 3.5)	11.3 ( $\pm$ 5.2)
<b>p-Value</b>	p=0.9	p=1.0	p=0.9

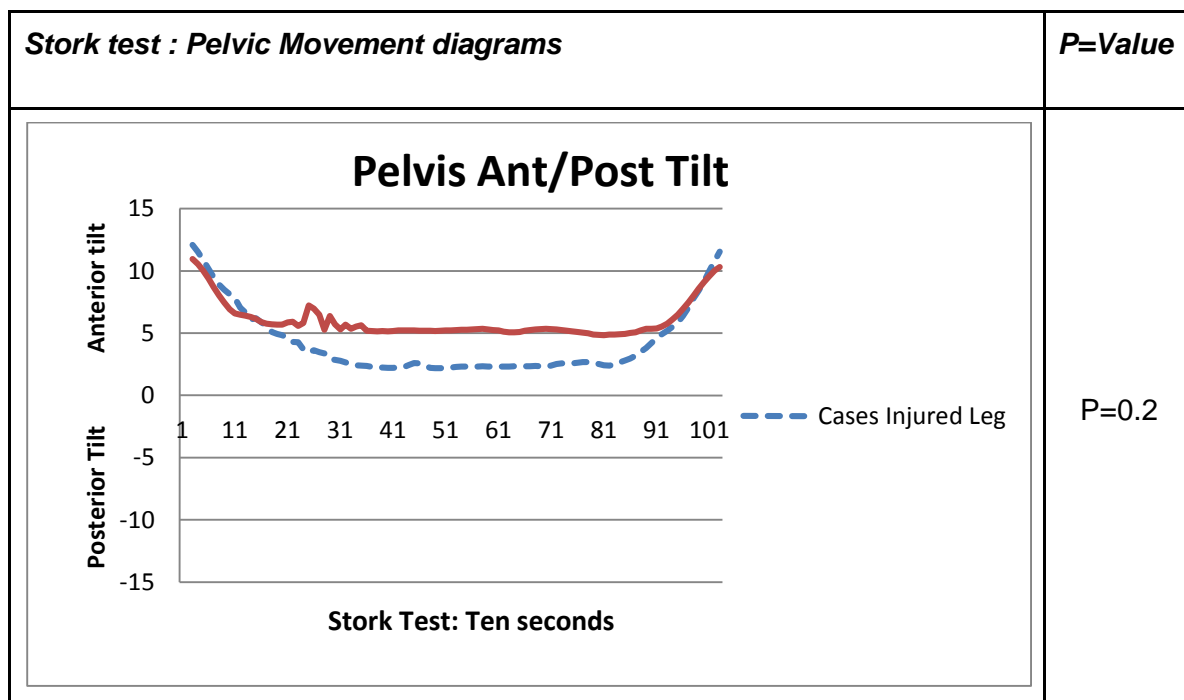
**3.2.1.3 Pelvic Anterior/Posterior Rotation**

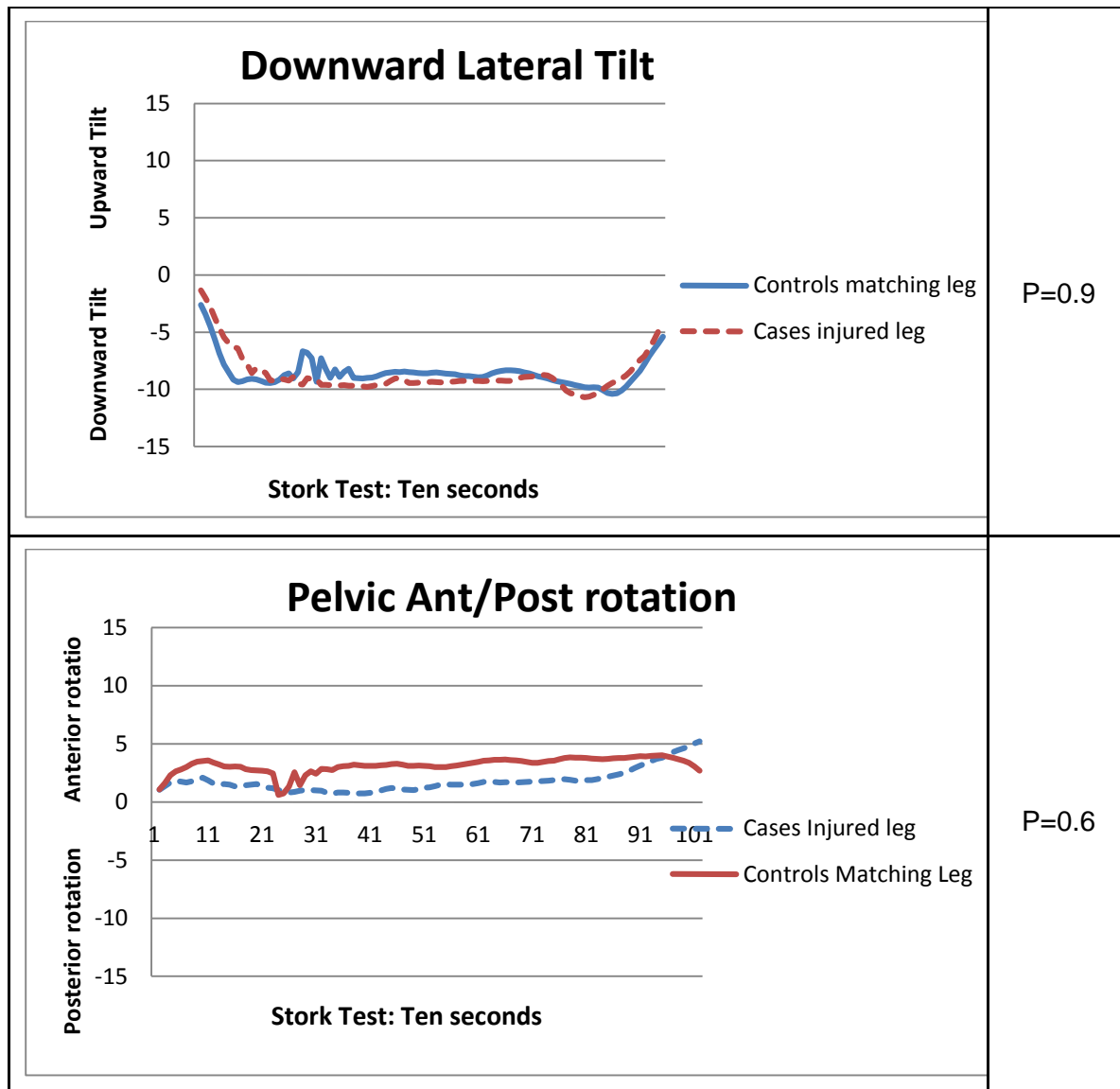
No significant difference was found in pelvic rotation between cases and their matched controls (p=0.6). (Table 5)

**Table 5: Pelvic rotation: Cases compared to Controls**

	<b>Peak anterior pelvic rotation</b> Mean (SD)	<b>Peak posterior pelvic rotation</b> Mean (SD)	<b>Total Range of motion: Pelvis ant/post rotation</b> Mean (SD)
<b>Cases (n=9)</b>	6.1 (± 3.7)	-1.3 (± 2.7)	7.4 (± 2.9)
<b>Controls (n=9)</b>	5.3 (± 4.5)	-1.1 (± 5.3)	6.3 (± 4.6)
<b>p-Value</b>	p=0.7	p=0.9	p=0.6

**Figure 3: Pelvic Movement Diagrams**





### 3.2.2 Hip Kinematics

*Hip Kinematics cases' injured side compared to matching side of controls*

#### 3.2.2.1 Hip Flexion/Extension

No statistically significant changes were found in the hip flexion or extension angles of cases compared to their matched controls were ( $p=0.9$ ). (Table 6)

**Table 6: Hip Flexion/Extension: Cases compared to matched Controls**

	<b>Peak Hip Flexion angle</b> Mean (SD)	<b>Peak Hip Extension angle</b> Mean (SD)	<b>Range of motion: Hip Flexion/Extension</b> Mean (SD)
<b>Cases (n=9)</b>	12.7 ( $\pm$ 8.0)	2.1 ( $\pm$ 9.4)	10.5 ( $\pm$ 3.8)
<b>Controls (n=9)</b>	15.4 ( $\pm$ 9.1)	5.3 ( $\pm$ 6.6)	10.1 ( $\pm$ 5.6)
<b>p-Value</b>	p=0.5	p=0.4	p=0.9

**3.2.2.2 Hip Adduction/Abduction**

No significant differences were found in Hip abduction/adduction angles cases compared to matched controls (p=0.5). (Table 7)

**Table 7: Hip abduction/Adduction: Cases compared to matched controls**

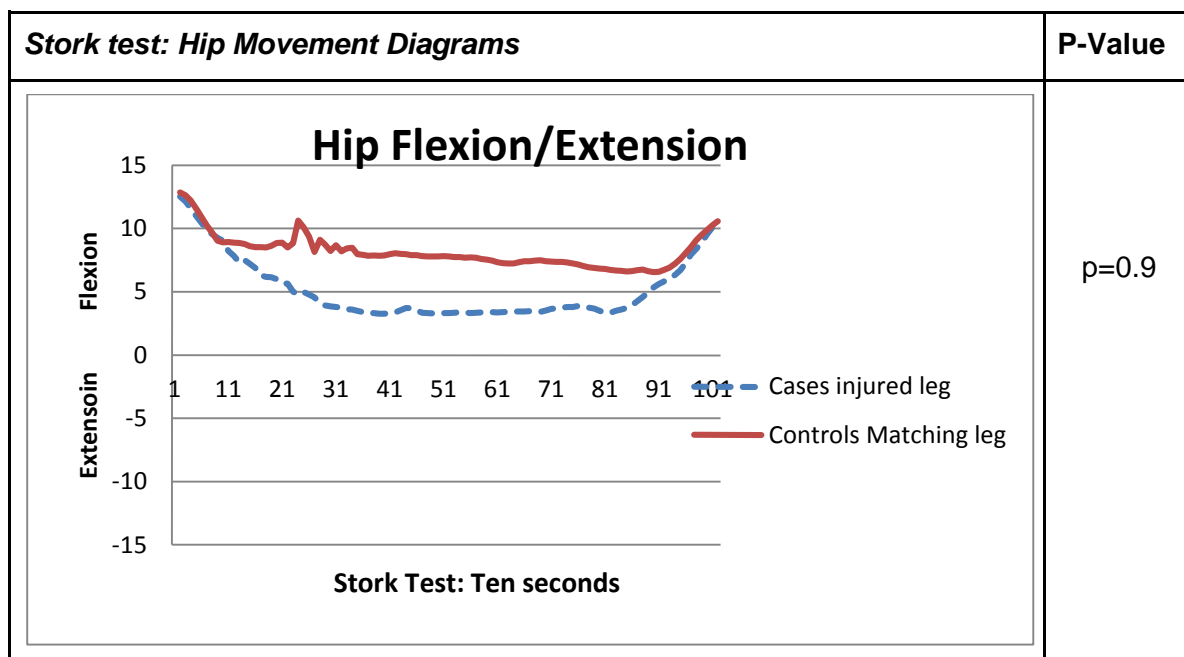
	<b>Peak Hip Adduction angle</b> Mean (SD)	<b>Peak Hip Abduction angle</b> Mean (SD)	<b>Range of motion: Hip Abduction/Adduction</b> Mean (SD)
<b>Cases (n=9)</b>	1.9 ( $\pm$ 3.1)	-8.0 ( $\pm$ 3.4)	9.9 ( $\pm$ 2.5)
<b>Controls (n=9)</b>	2.6 ( $\pm$ 6.1)	-9.0 ( $\pm$ 2.6)	11.6 ( $\pm$ 7.3)
<b>p-Value</b>	p=0.8	p=0.5	p=0.5

**3.2.2.3 Hip Internal/External Rotation**

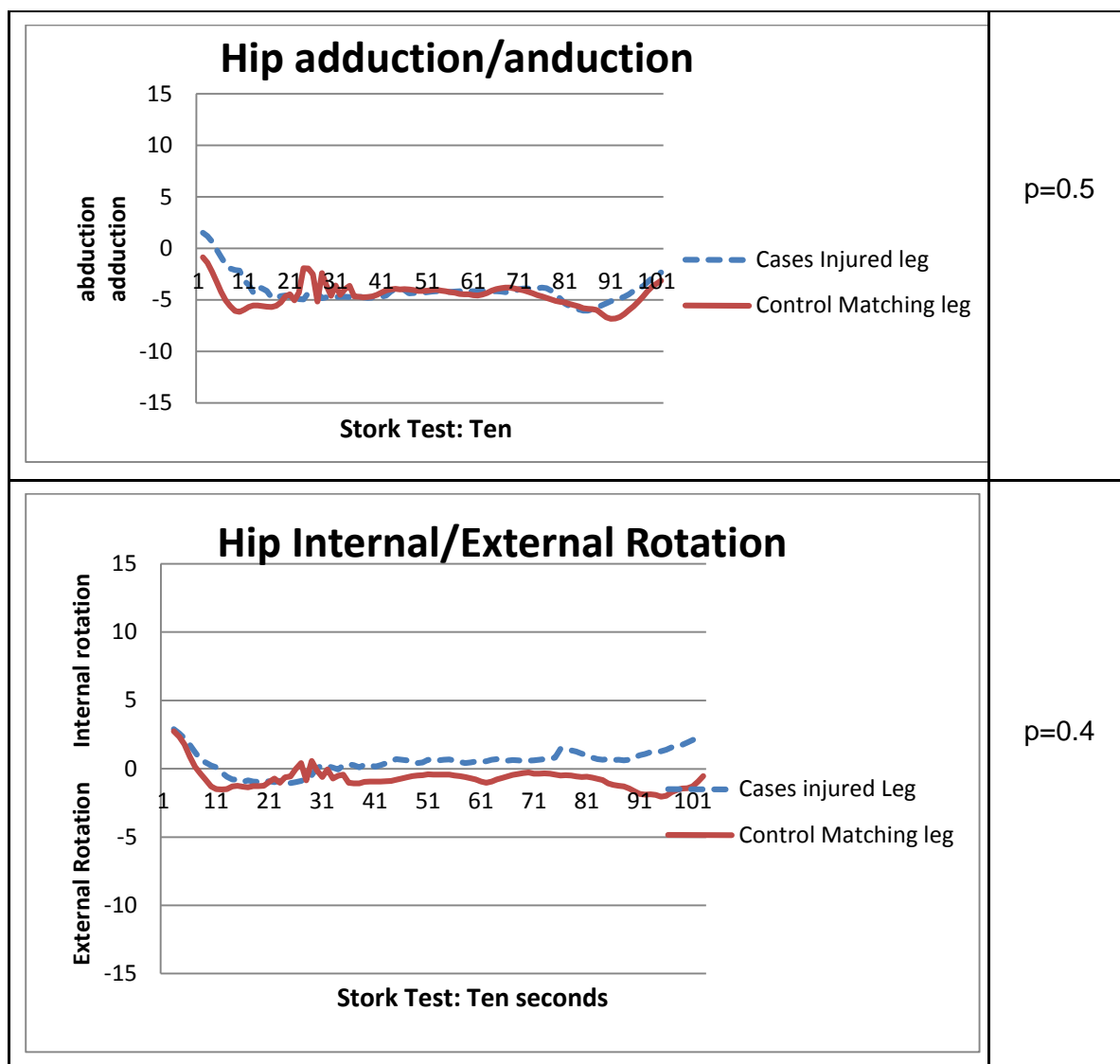
No significant changes were found in the internal/External angles of hip rotation with cases compared to their matched controls (p=0.4). (Table 8)

**Table 8: Hip internal/external rotation: Cases compared to matched controls**

	Peak Hip Internal rotation angle Mean (SD)	Peak Hip External rotation angle Mean (SD)	Range of motion: Hip rotation Mean (SD)
<b>Cases (n=9)</b>	4.5 ( $\pm$ 9.2)	-2.5 ( $\pm$ 6.0)	6.9 ( $\pm$ 4.4)
<b>Controls (n=9)</b>	4.6 ( $\pm$ 9.1)	-4.0 ( $\pm$ 8.6)	8.7 ( $\pm$ 4.2)
<b>p-Value</b>	p=1.0	p=0.7	p=0.4

**Figure 4: Hip Movement diagrams**






During the analysis of the data a single control subject was seen to be an outlier in data. Data was analysed again without the subject to see if result differ.

The outlier demonstrated twice and even three times the amount of range of motion compared to the other subjects.

### 3.2.3 Pelvic Kinematics

*Groin pain cases' injured side compared to the matching side of their controls*

#### 3.2.3.1 Pelvic Anterior/Posterior Tilt

A significant increase in the total range of motion for anterior/posterior pelvic tilt was observed ( $p=0.03$ ) during the ten second Stork Test. (Table 9)

**Table 9: Pelvic anterior/posterior tilt without outlier six: cases compared to matched controls**

	<b>Peak anterior pelvic tilt angles</b> Mean (SD)	<b>Peak posterior pelvic tilt angles</b> Mean (SD)	<b>Range of motion: Ant/Post pelvic tilt</b> Mean (SD)
<b>Cases (n=9)</b>	12.68 ( $\pm$ 5.86)	1.28 ( $\pm$ 6.47)	11.40 ( $\pm$ 2.95)
<b>Controls (n=8)</b>	10.95 ( $\pm$ 3.93)	3.01 ( $\pm$ 4.25)	7.94 ( $\pm$ 2.88)
<b>p-Value</b>	$p=0.49$	$p=0.53$	$p=0.03$
<b>Effect size</b>			1.26

### 3.2.3.2 Pelvic Lateral Tilt

No significant differences were found in the lateral pelvic tilt angles cases compared to their matched controls ( $p=0.35$ ). (Table 10)

**Table 10: Pelvic lateral tilt without outlier six: Cases compared to matched controls**

	<b>Peak upward pelvic tilt angles</b> Mean (SD)	<b>Peak downward pelvic tilt angles</b> Mean (SD)	<b>Range of motion: Lateral Pelvic tilt</b> Mean (SD)
<b>Cases (n=9)</b>	-1.08 ( $\pm$ 3.49)	-12.11 ( $\pm$ 3.21)	11.03 ( $\pm$ 2.98)
<b>Controls (n=8)</b>	-2.02 ( $\pm$ 2.50)	-11.73 ( $\pm$ 3.51)	9.72 ( $\pm$ 2.53)
<b>p-Value</b>	$p=0.54$	$p=0.82$	$p=0.35$

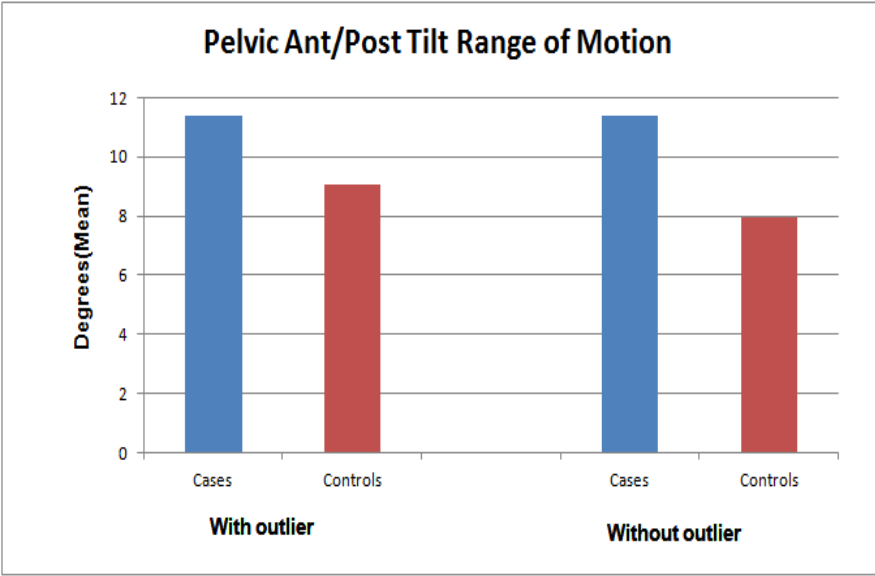
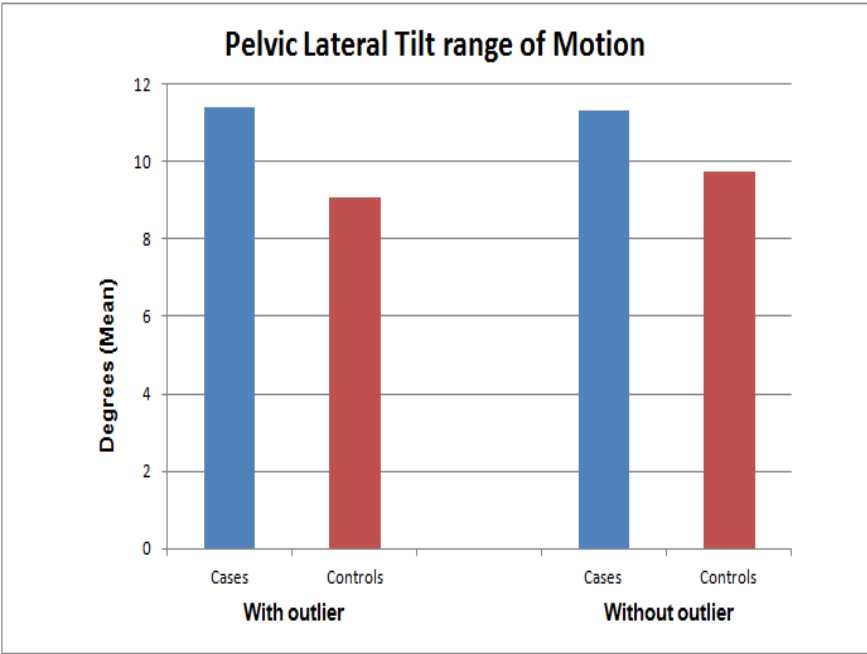
### 3.2.3.3 Pelvic Anterior/Posterior Rotation

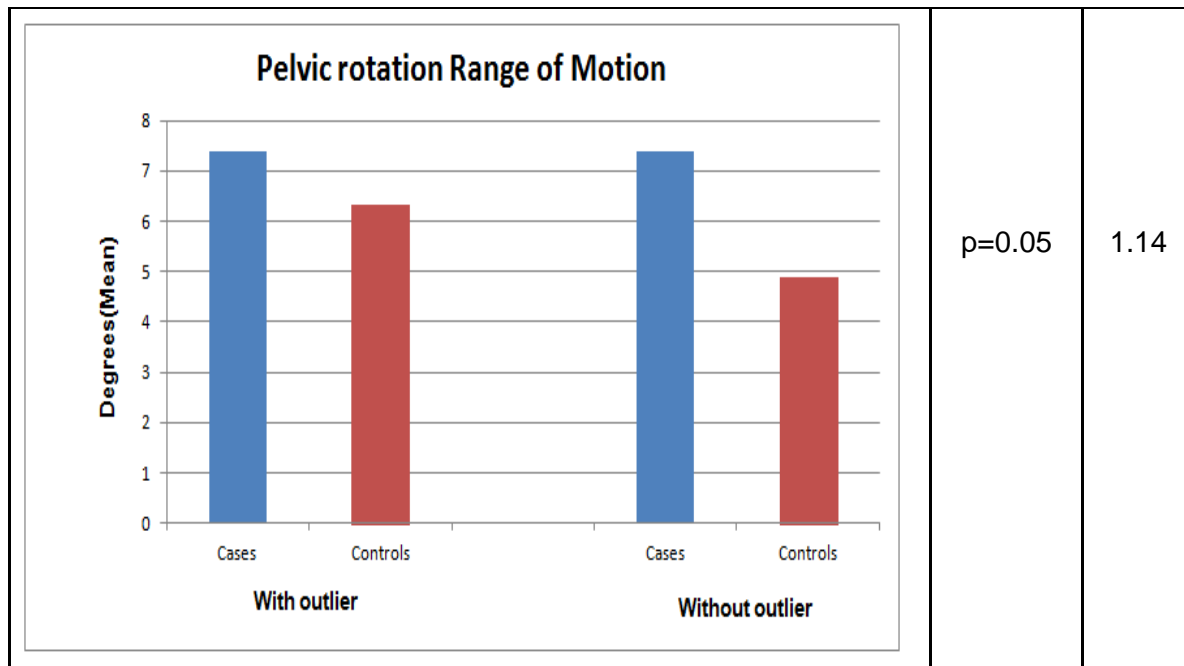
A moderately significant difference ( $p=0.05$ ) was found in the total range of motion of pelvic anterior/posterior rotation with cases compared to their matched controls. A  $2.5^\circ$  increase in range of motion was found in the cases. (Table 11)

**Table 11: Pelvic anterior/posterior rotation: Cases compared to matched controls**

	<b>Peak anterior pelvic rotation</b> Mean (SD)	<b>Peak posterior pelvic rotation</b> Mean (SD)	<b>Total Range of motion: Pelvic rotation</b> Mean (SD)
<b>Cases (n=9)</b>	6.14 ( $\pm$ 3.70)	-1.25 ( $\pm$ 2.68)	7.39 ( $\pm$ 2.87)
<b>Controls (n=8)</b>	4.98 ( $\pm$ 4.68)	0.09 ( $\pm$ 4.24)	4.89 ( $\pm$ 1.62)
<b>p-Value</b>	$p=0.58$	$p=0.44$	$p=0.05$
<b>Effect size</b>			1.14

**Figure 5: Pelvic movement of cases compared to controls, with and without outlier**

<i><b>Pelvic movement graph</b></i>	<i><b>P-Value</b></i>	<i><b>Effect size</b></i>									
 <p><b>Pelvic Ant/Post Tilt Range of Motion</b></p> <table border="1"> <thead> <tr> <th>Condition</th> <th>Cases (Mean Degrees)</th> <th>Controls (Mean Degrees)</th> </tr> </thead> <tbody> <tr> <td>With outlier</td> <td>~11.5</td> <td>~9.0</td> </tr> <tr> <td>Without outlier</td> <td>~11.5</td> <td>~8.0</td> </tr> </tbody> </table>	Condition	Cases (Mean Degrees)	Controls (Mean Degrees)	With outlier	~11.5	~9.0	Without outlier	~11.5	~8.0	p=0.03	1.26
Condition	Cases (Mean Degrees)	Controls (Mean Degrees)									
With outlier	~11.5	~9.0									
Without outlier	~11.5	~8.0									
 <p><b>Pelvic Lateral Tilt range of Motion</b></p> <table border="1"> <thead> <tr> <th>Condition</th> <th>Cases (Mean Degrees)</th> <th>Controls (Mean Degrees)</th> </tr> </thead> <tbody> <tr> <td>With outlier</td> <td>~11.5</td> <td>~9.0</td> </tr> <tr> <td>Without outlier</td> <td>~11.5</td> <td>~9.8</td> </tr> </tbody> </table>	Condition	Cases (Mean Degrees)	Controls (Mean Degrees)	With outlier	~11.5	~9.0	Without outlier	~11.5	~9.8	p=0.35	
Condition	Cases (Mean Degrees)	Controls (Mean Degrees)									
With outlier	~11.5	~9.0									
Without outlier	~11.5	~9.8									



### 3.2.4 Hip Kinematics

*Hip Kinematics cases' injured side compared to matching side of controls*

#### 3.2.4.1 Hip Flexion/Extension

No significant differences were found in Hip Flexion/Extension angles cases compared to matched controls (p=0.29). (Table 12)

**Table 12: Hip flexion/extension without outlier 6: Cases compared to matched controls**

	Peak Hip Flexion angle Mean (SD)	Peak Hip Extension angle Mean (SD)	Range of motion: Hip Flexion/Extension Mean (SD)
<b>Cases (n=9)</b>	12.66 (± 7.99)	2.11 (± 9.42)	10.54 (± 3.76)
<b>Controls (n=8)</b>	13.35 (± 7.19)	4.73 (± 6.79)	8.62 (± 3.47)
<b>p-Value</b>	p=0.85	p=0.53	p=0.29

### 3.2.4.2 Hip abduction/adduction angles

No significant changes were found in the hip abduction/adduction angles cases compared to matched controls ( $p=0.64$ ). (Table 13)

**Table 13: Hip abduction/adduction without outlier 6: Cases compared to matched controls**

	<b>Peak Hip Adduction angle</b> Mean (SD)	<b>Peak Hip Abduction angle</b> Mean (SD)	<b>Range of motion: Hip Abd/Add</b> Mean (SD)
<b>Cases (n=9)</b>	1.90 ( $\pm$ 3.10)	-8.00 ( $\pm$ 3.35)	9.91 ( $\pm$ 2.48)
<b>Controls (n=8)</b>	0.80 ( $\pm$ 2.87)	-8.50 ( $\pm$ 2.36)	9.30 ( $\pm$ 2.79)
<b>p-Value</b>	$p=0.46$	$p=0.73$	$p=0.64$

### 3.2.4.3 Hip Anterior/Posterior rotation

No significant changes were seen in the hip anterior/posterior rotation angles of cases compared to matched controls ( $p=0.69$ ). (Table 14)

**Table 14: Hip anterior/posterior rotation without outlier 6: Cases compared to matched controls**

	<b>Peak Hip Anterior rotation angle</b> Mean (SD)	<b>Peak Hip Posterior rotation angle</b> Mean (SD)	<b>Range of motion: Hip Rotation</b> Mean (SD)
<b>Cases (n=9)</b>	4.46 ( $\pm$ 9.15)	-2.48 ( $\pm$ 6.01)	6.94 ( $\pm$ 4.42)
<b>Controls (n=8)</b>	3.25 ( $\pm$ 8.63)	-4.48 ( $\pm$ 9.06)	7.73 ( $\pm$ 3.29)
<b>p-Value</b>	$p=0.78$	$p=0.60$	$p=0.69$

The main findings from the results above show the following:

1. With the outlier removed a statistically significant Increased in pelvic anterior/posterior tilt Range of motion was observed, when cases were compared to their matched healthy controls.
2. With the outlier removed a significant increase in pelvic anterior/posterior rotation was observed, when cases were compared to their matched healthy controls.
3. No significant changes were observed in the lateral pelvic tilt, or any angles measured at the hip, with or without the outlier, when cases were compared to their matched healthy controls.

## 4. Discussion

This is the first study to report on kinematic changes of the hip and pelvis in unilateral groin pain sports participants compared to their matched healthy controls during a 10 second Stork Test. A statistically significant increase in anterior/posterior pelvic tilt range of motion was observed after an outlier in the control group, control six, was removed from the data ( $p=0.03$ ). A very large effect size of 1.26 was found. There was also a moderately significant increase in the pelvic anterior/posterior rotation range of motion in the cases compared to their matched controls ( $p=0.05$ ), with a very large effect size of 1.14. No other angles from the hip or pelvis demonstrated any significant changes.

Stability of the hip and pelvis during functional activity is of vital importance. It forms the link between the upper body and the lower limbs during load and force transfer (Hungerford et al, 2007). A decrease in the stability of the hip and pelvis leads to a decrease in motor control strategies during movement, causing muscular imbalances and altered motor strategies during functional and sporting activities (Morrissey 2012; Tyler 2010; Bowman et al, 2010; Almeida et al, 2013). This altered motor control pattern may lead to changes in muscle pattern activation, resulting in altered pelvic tilts or translation (Hungerford et al, 2007).

A statistically significant increase in the total range of motion was observed in the pelvic anterior/posterior tilt. In both the anterior and posterior tilt angles the cases showed increased ranges compared to their controls, but neither was statistically significant. The increase of pelvic tilt range of motion may be due to a decrease in abdominal strength that is responsible for stabilising the pelvis during anterior/posterior tilting, decreasing stability during the 10 second static Stork Test. In a study done by Neumann (2010) it was found that during hip flexion above  $90^\circ$ , the hip flexors start to create a parallel force on the hip and pelvis. As the hip flexes to a  $90^\circ$  and above, this force increases. If the antagonist muscle (abdominals) has a decreased ability to counter this pull, the pelvis then becomes unstable.



This parallel force causes a rotation of the femur in relation to the pelvis or the pelvis in relation to the femur. In patients with chronic adductor-related groin pain, transverse abdominis has been shown to have a delayed activation time compared to uninjured controls (Cowan et al, 2014). The delayed onset of the transverse abdominis activation in participants with adductor-related groin pain may create a decreased muscle control of the pelvis with decreased motor control enabling the hip flexors to pull the pelvis into further anterior rotation as well as decreased ability to control the pelvis into posterior rotation (Mosler et al, 2015).

A significant increase in pelvis anterior/posterior rotation was observed for the unilateral groin pain cases compared to their matched controls ( $p=0.05$ ). The cases demonstrated to be in a slight degree of external pelvic rotation (-1, 25 degrees) compared to the controls who remained in relative neutral pelvic rotation (0.09 degrees) throughout the test procedure. This may be owing to altered motor control of the hip and pelvis in the unilateral groin pain group. At the hip and pelvis the gluteus maximus forms the primary external rotator; the secondary external rotators are gluteus medius, minimus and obturator externus, sartorius and biceps femoris (Neumann 2010). These secondary, short muscles produce an effective external rotational force to provide stability of the pelvis during movement (Neumann, 2010). A reduction in the gluteus medius activation may imply a decreased ability of the hip to maintain or control external rotation during the Stork Test. According to a study by Morrissey (2012), patients with chronic adductor related groin pain had significant reductions in the activation of the gluteus medius muscle during all stages of a single leg stance, with 90° hip flexion, when compared to their matched controls.

No other statistically significant changes were observed in the cases compared to their matched healthy controls. The peak angles, minimum angles and total range of motion at the hip in all planes showed no significant changes, with or without the outlier data. At the pelvis no significant differences were seen in the lateral tilt with or without the outlier.

The results of this research may have implications in everyday clinical evaluation. The decreased ability to maintain stability of the hip and pelvis during the Stork test could indicate dysfunction or weakness in certain stabilising muscle groups, possibly leading the physiotherapist in a direction for more effective treatment and rehabilitation. To substantiate this, future studies should include EMG testing of the muscle groups surrounding the hip and pelvis.

Certain limitations should be considered for the current study: the small sample size and the limit such a small sample has on making conclusions for a larger population of active unilateral groin pain sports participant populations. Another limitation of the current study is the comparability of the data to a larger groin pain population owing to the use of consecutive sampling. Leg dominance was not matched in the study due to practical limitations, but could be valuable due to different balancing strategies players could have for their dominant and non-dominant legs.

Recommendations for future studies include using random selection of sports clubs to increase the comparability of the data. Owing to the nature of the study and the vast influence musculature has on the stability of the pelvis and hip, we recommend that in future studies EMG measurements of the major muscle groups be included to evaluate the effect they have on the kinematical changes. Some of the major muscle groups could include gluteus medius, adductors, rectus femoris, transverse abdominis and hamstrings. We also recommend that future studies include administering the Stork Test when the participant's musculature is in a more fatigued state. A study by Johnston et al (1998) finds a significant difference in the ability of healthy participants to do a static test after the onset of fatigue of lower limb muscles, showing a decrease in the ability of participants to keep their balance and muscle control during a static test. A reduction in muscle control from fatigue may increase the degree of joint instability, making kinematic differences more pronounced. During normal sporting activity of the participants in this study, muscle fatigue takes place in

the course of a match or training session. Knowing the influence that fatigue may have on kinematics, may alter evaluation and treatment.

## 5. Conclusion

The aim of this study has been to determine whether there are any differences in the 3D kinematics of the hip and pelvis during a Stork Test in sports participants with and adductor related groin pain compared to healthy matched controls. Initially we found no significant differences in any of the planes. However, post hoc analysis, which excluded an outlier in the control group, showed a significant increase of the Pelvis range of motion in the sagittal plane of cases as well as a marginal difference in the transverse plane range of motion of the pelvis. It might be deduced that the groin pain patients have a decreased ability to activate the stabilisers of the pelvis, adductors, abdominals and gluteus medius, in order to stabilise the pelvis during the movement. A possible reason for the decreased muscle control in the affected group is most likely owing to decreased muscle strength or muscle inhibition because of pain. Future research should focus on exploring these muscular components during the Stork Test, perhaps making use of EMG.

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## Chapter 4: Conclusions, Limitations and Recommendations

The main aim of this study has been to determine if there are 3D pelvic and hip kinematic differences between sports participants with unilateral groin pain when compared to matched healthy controls. The main findings indicated that sports participants with groin pain demonstrated increased total range of motion of pelvic tilt in the sagittal plane during the Stork Test compared to healthy controls. We also found a statistically significant increase in the total range of motion of pelvic anterior/posterior rotation in the transverse plane in cases compared to their matched healthy controls. Because of the type of study design used in our study, it is uncertain whether these differences are owing to a cause or consequence of groin pain. The information gained from this study suggests that pelvic kinematics should be considered in the assessment of groin injuries.

The aetiology of groin injuries is multifactorial and could be coexisting with other pathological processes (Mosler et al, 2015). It is speculated that groin pain may be related to motor control strategies at the hip and pelvis during load transfer to the lower limbs (Morrissey 2012). Altered motor strategies or muscle pattern activation at the hip and pelvis during functional and recreational activities may lead to decreased motor control during the load transfer, causing the stabilising muscle, such as the abdominals, gluteus medius, gluteus maximus and adductor longus, to have less control over the movement of the hip and pelvis. For single leg weight bearing it is of vital importance for the hip musculature to have a good contraction, creating a more stable hip and pelvis for better load transfer to the lower limbs. Normal kinematics of the pelvis, as well as pelvic stability during weight transfer, is thus influenced by the muscles surrounding the pelvis. Decreased muscle strength and activation may lead to the decreased ability of the hip and pelvis to maintain a position during a functional or recreational movement, creating altered kinematics of these joints'ability to



maintain the desired position. The assessment of pelvic stability during activities that induce load transfer across the pelvic articulation is thus highly recommended to evaluate these altered patterns while addressing them with the correct rehabilitation (Hungerford et al, 2007).

## **Conclusion**

The aim of this study was to determine if there were any kinematic differences in the hip and pelvis in active sports participating unilateral groin pain participants compared to their healthy matched controls during a ten second Stork test. There was significantly more range of motion in pelvis anterior/posterior tilting as well as significantly increased range of motion in the pelvis anterior/posterior rotation. A possible reason for the increase in range of motion is a decrease in the stability of the pelvis during load and force transfer from the upper body to the lower limbs. This decrease in stability may be a result of a decrease in muscular control around the hip and pelvis.

## **Clinical implications**

Clinically the information gathered from this study could be used to facilitate or rehabilitate musculature around the hip and pelvis to increase stability during functional and recreational activities. This enables clinicians to rehabilitate the correct muscles and muscular control to decrease pain and prevent re-injury. As found in the data, an increase in pelvic anterior/posterior tilt range of motion, as well as increased anterior/posterior rotation, was found. This information would be used to better rehabilitate or facilitate the stabilising muscle groups to decrease the strain on the adductor muscle group.

## **Limitations**

Certain limitations need to be considered in the current study;

During this study a relatively small sample size was used, which may not give a true reflection of the kinematics associated with chronic groin pain, limiting the validity of these findings.

During the analysis of the data, leg dominance was not included or matched because of practical limitations; previous data used as part of the bigger study did not specify the leg dominance of the participants. It is possible that the balance strategy during the static ten second Stork Test might differ between the dominant and non-dominant leg.

Random sampling was not used during the recruitment for the study, which may not be a clear representation of the groin pain population.

In our study the focus was on the pelvis and the hip joint kinematics; other regional analysis will be done in separate articles by co-researchers. Therefore the kinematics of the other regions (trunk; knee; ankle) was not taken into account in the interpretation of the findings.

### **Recommendations:**

Future research should include the exploration of muscular components around the hip and pelvis, allowing insight into the effect musculature has on the hip and pelvis stability during a ten second Stork Test. As stated in the literature review for this study, the muscular components of the hip and pelvis play a major role in the stabilisation and kinematics of these joints. It would therefore be of vital importance to include investigation of this component in future research. Possibly with Electromyography (EMG) to give more clarity on muscular function and their possible cause of the Groin pain.

It is suggested that in future studies, bigger sample sizes should be used to increase the confidence levels of the data.

In future studies random sampling of sports clubs should be used to increase the representation of the unilateral groin pain population.

It is suggested that in future studies, the leg dominance of the participants should be taken into account. Owing to the altered motor control strategies, the participants may have to balance on their dominant and non-dominant legs.

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## Appendix A: Journal Guidelines

### Journal for physiotherapy in sport

#### GUIDE FOR AUTHORS

##### *Your Paper Your Way*

We now differentiate between the requirements for new and revised submissions. You may choose to submit your manuscript as a single Word or PDF file to be used in the refereeing process. Only when your paper is at the revision stage, will you be requested to put your paper in to a 'correct format' for acceptance and provide the items required for the publication of your article.

**To find out more, please visit the Preparation section below.**

The editor, Zoe Hudson, PhD, welcomes the submission of articles for publication in the journal.

##### *Types of paper*

**Original Research:** Provide a full length account of original research and will not normally exceed 4000 words.

**Review Papers:** Provide an in-depth and up to date critical review of a related topic and will not normally exceed 4000 words.

**Case Studies:** A case report providing clinical findings, management and outcome with reference to related literature.

**Masterclasses:** Usually a commissioned piece by an expert in their field. If you would like to submit a non-commissioned article, please check with the editorial office beforehand.

**Clinical Approaches:** These include clinical approaches or opinions which may be novel or practiced with minimal evidence available in the literature.

**Professional Issues:** An occasional series which aims to highlight changes in guidelines or other professional issues. These word counts include Keywords, Acknowledgements and the references contained within the article. The reference list at the end of the article, the

Abstract, figures/tables, title and author information and Appendices are not included in the word count.

## **BEFORE YOU BEGIN**

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For information on Ethics in publishing and Ethical guidelines for journal publication see

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If the work involves the use of animal or human subjects, the author should ensure that the work described has been carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki); Recommendations guiding physicians in biomedical research <http://www.wma.net/en/30publications/10policies/b3/index.html>.

Adopted by the 18th World Medical Assembly, Helsinki, Finland, June 1964, amended by the 29th World Medical Assembly, Tokyo, Japan, October 1975, the 35th World Medical Assembly, Venice, Italy, October 1983, and the 41st World Medical Assembly, Hong Kong, September 1989. EU Directive 2010/63/EU for animal experiments [http://ec.europa.eu/environment/chemicals/lab\\_animals/legislation\\_en.htm](http://ec.europa.eu/environment/chemicals/lab_animals/legislation_en.htm); Uniform

Requirements for manuscripts submitted to Biomedical journals <http://www.icmje.org>. The manuscript should contain a statement that has been approved by the appropriate ethical committees related to the institution(s) in which it was performed and that subjects gave informed consent to the work. Studies involving experiments with animals must state that their care was in accordance with institution guidelines. Patients' and volunteers' names, initials, and hospital numbers should not be used. In a case report, the subject's written consent should be provided. It is the author's responsibility to ensure all appropriate consents have been obtained. Photographs of human participants are acceptable if the authors have received appropriate permission for publication of the photographs, or taken appropriate measures to disguise the individual's identity.

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All authors must disclose any financial and personal relationships with other people or organizations that could inappropriately influence (bias) their work. Examples of potential



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All authors should have made substantial contributions to all of the following: (1) the conception and design of the study, or acquisition of data, or analysis and interpretation of data, (2) drafting the article or revising it critically for important intellectual content, (3) final approval of the version to be submitted. In the covering letter to the editorial office, we ask

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### ***New guidance for randomised controlled trials***

*Physical Therapy in Sport* has adopted the proposal from the International Committee of Medical Journal Editors (ICMJE) (see a recent Editorial in *Manual Therapy* <http://www.sciencedirect.com/science/article/pii/S1356689X1200238X>, Editorial: "Clinical trial registration in physiotherapy journals: Recommendations from the International Society of Physiotherapy Journal Editors"), which requires, as a condition of consideration for publication of clinical trials, registration in a public trials registry. Trials must register at or before the onset of patient enrolment. The clinical trial registration number should be included at the end of the abstract of the article. For this purpose, a clinical trial is defined as any research project that prospectively assigns human subjects to intervention or

comparison groups to study the cause and effect relationship between a medical intervention and a health outcome. Studies designed for other purposes, such as to study pharmacokinetics or major toxicity (e.g. phase I trials) would be exempt. Further information can be found at <http://www.icmje.org>. Clinical Trials that commence after 1st June 2013 must be registered to be considered for publication in *Physical Therapy in Sport*. Authors will be asked to state the trial registration number during the submission system as well as at the end of the manuscript file. From January 2014 *Physical Therapy in Sport* will not be able to accept any unregistered Clinical Trial papers. By 2015 the journal will not be able to publish any Clinical Trials that are unregistered prior to recruitment of the first participant.

### ***Reporting clinical trials (CONSORT)***

Randomized controlled trials should be presented according to the CONSORT guidelines. At manuscript submission, it may be helpful to authors to complete the CONSORT checklist and flow chart. The CONSORT checklist and template flow diagram can be found on <http://www.consort-statement.org>.

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- Abstract
- Keywords
- Text
- References
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#### Further instructions regarding the Text

- Do not use 'he', 'his' etc. where the sex of the person is unknown; say 'the participant', etc.

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Herrington, L., and Munro, A. (2010). Drop jump landing knee valgus angle; normative data in a physically active population. *Physical Therapy in Sport*, 11, 56-59

Reference to a book:

Magee, D.J. (1997). *Orthopaedic physical assessment*. (3rd ed.). Philadelphia: Saunders.

Reference to a chapter in an edited book:

Hudson, Z., & Brown, A. (2003). Athletes with disability. In: G. S. Kolt, & L. Snyder-Mackler (Eds.), *Physical therapies in sport and exercise* (pp. 521-304). Edinburgh: Churchill **Audio**

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<http://dx.doi.org/10.1016/j.physletb.2010.09.059>

When you use a DOI to create links to documents on the web, the DOIs are guaranteed never to change.

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### **AUTHOR INQUIRIES**

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## Appendix B: Adductor squeeze test

The adductor squeeze test is a pain provocation test which has shown to be a positive predictive value of chronic groin pain (Crow et al, 2010) and will be used to identify groin pain. Participants will be positioned in a crook-lying position with a single pillow under the head and arms folded cross their chest. The participant's hips will be positioned in 45° of flexion with both knees flexed to 90° (verified with a universal goniometer) and hips in neutral rotation. The same sphygmomanometer will be used for all participants. It will be pre-inflated to 10 mmHg and placed between the participants knees such that the middle third of the cuff will be located at the most prominent point of the medial femoral condyles (as seen in Figure 2). For testing the participant will be instructed to squeeze the cuff as hard as possible and maintain the squeeze for 10 seconds before returning to relaxed position. The highest pressure value displayed on the sphygmomanometer dial will be recorded during each maximal adductor squeeze test. A 2 min rest period will be allowed between each of the three trials. (Nevin et al, 2014).



## Appendix C: Ethics Approval



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### Ethics Letter

26-Jan-2015

Ethics Reference #: S12/10/265

Clinical Trial Reference #:

Title: Exploration of Biomechanics during functional Activities in Adults Sports participants with Chronic Groin Pain

Dear Ms Tracy MORRIS,

The HREC approved your application for a Protocol Amendment dated 2 October 2014.

Approval was also granted for the new research team for the extended study namely:

Principal Investigator:  
PROF Q LOUW

M Students:  
ERNESTINE BRUINDERS  
WENDY-LYNN MOODIEN  
ANICA COETSEE  
CHARIS WHITEBOOI  
CATHRINE DU PLESSIS

Supervisors:  
DR SJAN MARI VAN NIEKERK  
DR YOLANDI BRINK  
MS GAKEEMAH INGLIS JASSIEM  
MR JOHN COCKCROFT  
DR MARIANNE UNGER  
MS MARLETTE BURGER  
MS LEONE WILLIAMS WILLIAMS

If you have any queries or need further assistance, please contact the HREC Office 219389156.

Sincerely,

REC Coordinator  
Franklin Weber  
Health Research Ethics Committee 1

## Appendix D: Information leaflet

### PARTICIPANT INFORMATION LEAFLET

You are herewith invited participate in a research project. The study is aimed at analysing the lower limb movements of soccer and rugby players that have chronic groin injuries and comparing them to players that are uninjured. This will allow for a greater understanding as to the possible causing/ contributing factors of a groin injury.

Please take some time to read the information presented here, which will explain the details of this project. Please feel free to contact the **Principal Investigators** should any questions about any part of this project, should you not fully understand. It is very important that you clearly understand what this research entails and how you would be involved.

Your participation is **entirely voluntary** and you are free to decline to participate. If you say no, this will not affect you negatively in any way whatsoever. You are also free to withdraw from the study at any point, even if you do agree to take part.

This study has been approved by the **Health Research Ethics Committee at Stellenbosch University** and will be conducted according to the ethical guidelines and principles of the international Declaration of Helsinki, South African Guidelines for Good Clinical Practice and the Medical Research Council (MRC) Ethical Guidelines for Research.

PRINCIPAL INVESTIGATORS	CONTACT NUMBER
Ernestine Bruinders	072 435 7749
Wendy-Lynn Moodien	083 965 2057
Anica Coetsee	083 377 6831
Charis Whitebooi	082 826 5565
Catherine Du Plessis	074 176 8747

### Title

The kinematic and kinetic differences in athletes with chronic adductor related groin pain.

### Introduction

Groin pain is a common complaint amongst athletes and with a higher prevalence in athletes partaking in sports that involve sprinting, twisting, kicking and rapid change in direction (Jansen et al 2008, Patel et al 2011). Adductor strain-related injuries account for 58% of sport related groin injuries with the tendon of adductor longus being involved most frequently (Hölmich et al 2007, Sedaghati et al 2013, Gill et al 2014). Adductor strains can either be due to a traumatic mechanism such as forced abduction of the hip or as a result of repetitive

strain of the adductor muscle (Machotka 2009, Hackney 2012). An athlete with a previous adductor strain injury is twice as likely to experience recurring injuries in the groin (Engebretsen et al 2010). Groin injury is susceptible to chronicity and recurrence, however remains inadequately defined and lacks clear diagnostic measures (Crow et al 2010).

There is poor understanding of the mechanism of chronic groin pain and the association thereof with biomechanical risk factors of the pelvis and lower limb (Morrissey et al 2012). A study by Morrissey et al (2012) found a significant reduction in the ratio of gluteus medius and adductor longus activation during standing hip flexion (pelican stance) due to injured subjects having a marked reduction in gluteus medius activation pattern. Furthermore they made a finding which noted the injury-associated muscle imbalance to be present when testing the uninjured leg of injured subjects which could have been a reflection of predisposition to injury or the bilateral effect of groin injury (Morrissey et al 2012).

The purpose of this study is to explore the 3D kinematics, EMG activation patterns and ground reaction forces of the pelvis, hip, knee and ankle in active rugby and soccer players with chronic groin pain compared with asymptomatic controls.

### **Research Question**

What are the biomechanical differences of the lower quadrant and trunk in athletes with chronic adductor-related groin pain during pelican stance and double leg landing compared to healthy controls?

### **Aims**

The aim of the study is to determine whether there are biomechanical differences in the lower quadrant and trunk among rugby and soccer playing athletes with chronic adductor related unilateral and/ or bilateral groin pain during pelican stance and double leg landing, compared to healthy controls.

### **Objectives**

1. To determine the kinematics (calculate joint moments) of the trunk, hip, knee and ankle using 3D motion analysis during pelican stance and the landing phase of the double leg jump on both the affected and unaffected sides.
2. To determine trunk, hip, and lower limb muscle activation patterns (EMG) during bilateral pelican stance and landing phase of double leg jump.
3. To determine the vertical ground reaction forces during the landing phase of the double leg jump.
4. To determine centre of pressure (postural sway) during bilateral pelican stance of both lower limbs respectively.
5. To determine centre of pressure (postural sway) during the landing phase of double leg jump.

## **Methodology**

Population: Males ranging from 18–55 years of age who actively participate in soccer and rugby.

Study setting: The Physiotherapy and FNB-3D Movement Analysis Laboratory, Stellenbosch University, Tygerberg Campus, Cape Town, South Africa.

Sample size: 30 participants, fifteen cases and fifteen asymptomatic matched controls, based on the inclusion and exclusion criteria for cases and control in table 1 and 2, respectively, as seen in Appendix A.

Sampling method: Convenience sampling will be performed to recruit participants from soccer and rugby clubs situated in the Cape Peninsula area, Western Cape, South Africa.

Diagnostic criteria: Subjective examination revealing unilateral or bilateral inguinal pain and a positive adductor squeeze test indicating adductor muscle related pain.

## **Measurement Tools**

Motion Analysis: An eight camera T-10 Vicon (Ltd) (Oxford, UK) system, with Nexus 1.4 116 software will be used to capture the trails.

Visual analogue scale (VAS): A self-reporting instrument on pain intensity.

Surface Electromyography (EMG): To measure the activation of muscles surrounding the pelvis, hip and knee joints during the pelican stance and landing phase of the double leg jump.

Force plate: This will be used to measure ground reaction forces in the landing phase of the double leg jump and postural sway during pelican stance.

## **Anticipated Risks**

There are no anticipated risks for the participants that will take part in this study.

## **Anticipated Benefits**

The study will provide insight into whether there are biomechanical differences in the lower quadrant and trunk among rugby and soccer playing athletes with chronic groin pain. This will facilitate the understanding of the possible aetiology of groin pain.

## **Ethical Considerations**

Approval for conducting the study will be obtained from the Committee of Human Research at Stellenbosch University. The study will be conducted according to the internationally accepted ethical standards and guidelines. Informed voluntary consent will be obtained from each participant. All the procedures will be explained to each participant and the results will be shared with them. A number will be allocated to each participant thereby ensuring their confidentiality. Consent will be obtained for the publication of results and the use of photographs taken during the study.



## Appendix E: Subjective Screening

Name: \_\_\_\_\_

Age: \_\_\_\_\_

<b>What sport do you play</b>	Rugby	Soccer
<b>How many hours do you spend training and participating in your sport per week</b>		
<b>Have you ever had any pain over your groin area?</b>	YES	NO
<b>Has the groin pain been there for longer than three months?</b>	YES	NO
<b>Is the groin pain currently stopping you from participating in sport?</b>	YES	NO
<b>Which side is your pain?</b> (It can be on both sides)	LEFT	RIGHT
<b>Do you feel generally healthy?</b>	YES	NO
<b>Do you have a history of neck, back, pelvis or limb injuries? If YES, please state</b>	YES Types of injuries: _____	NO
<b>Have you suffered from any of the symptoms related to prostatitis or urinary tract infection, as listed adjacently?</b>  <b>YES/ NO</b>	Pain and tenderness in upper back and sides.	Rectal pain.
	Pain in the pelvis, genitals, lower back and buttocks.	Discomfort in the perineal area (the area between the scrotum and the anus).

<b>Have you suffered from any symptoms associated with nerve entrapment syndrome in your legs?</b>	YES	NO
<b>Have you undergone any orthopaedic surgery, as listed adjacently in the last 12 months?</b>  <b>YES/ NO</b>	Lumbar spine	Pelvis
	Hip Joint	Knee joint
	Ankle joint	Foot
<b>Have you been diagnosed with any of the following illnesses?</b>  <b>YES/ NO</b>	Ankylosing Spondylosis;	Scheuerman's disease
	Rheumatoid Arthritis;	Muscular Dystrophy
	Paget's disease	

Thank you for your time. We will contact you in regards to forming part of the study.

Kind Regards

Anica, Franci, Ernestine, Wendy and Charis

## Appendix F: Objective Screening

### DAY OF TESTING

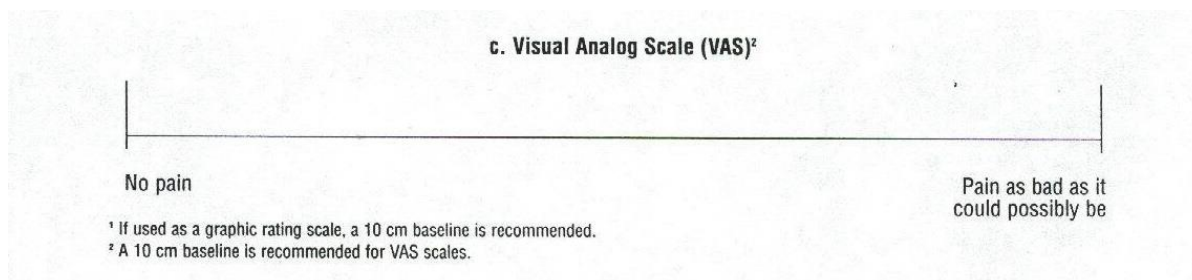
Participant: \_\_\_\_\_

Sport: \_\_\_\_\_

Date: \_\_\_\_\_

### VAS (Before tests)

Please indicate on the line the pain that you are CURRENTLY feeling:



**c. Visual Analog Scale (VAS)<sup>2</sup>**

No pain

Pain as bad as it could possibly be

<sup>1</sup> If used as a graphic rating scale, a 10 cm baseline is recommended.  
<sup>2</sup> A 10 cm baseline is recommended for VAS scales.

Height: \_\_\_\_\_

Weight: \_\_\_\_\_

Leg length: L \_\_\_\_\_ R \_\_\_\_\_

### Anthropometric measurements:

Knee: L \_\_\_\_\_ R \_\_\_\_\_

Ankle: L \_\_\_\_\_ R \_\_\_\_\_

<b>Hip</b>	Left1	Left2	Left3	<b>Mean</b>	Right1	Right2	Right3	<b>Mean</b>
Extension								
Flexion								
Abduction								
Adduction								
Internal Rotation								
External Rotation								

<b>Knee</b>	Left1	Left2	Left3	<b>Mean</b>	Right1	Right2	Right3	<b>Mean</b>
Extension								
Flexion								

<b>Ankle</b>	Left1	Left2	Left3	<b>Mean</b>	Right1	Right2	Right3	<b>Mean</b>
Dorsiflexion								
Plantar flexion								
Inversion								
Eversion								

## Appendix G: Consent form

### PARTICIPANT INFORMATION LEAFLET AND CONSENT FORM

#### TITLE OF THE RESEARCH PROJECT:

The kinematic and kinetic differences in athletes with chronic adductor related groin pain.

#### REFERENCE NUMBER:

PRINCIPAL INVESTIGATORS	CONTACT NUMBER
Ernestine Bruinders	072 435 7749
Wendy-Lynn Moodien	083 965 2057
Anica Coetsee	083 377 6831
Charis Whitebooi	082 826 5565
Catherine Du Plessis	074 176 8747

#### ADDRESS:

Stellenbosch University, Tygerberg Campus

You are herewith invited participate in a research project. Please take some time to read the information presented here, which will explain the details of this project. Please ask the study staff any questions about any part of this project that you do not fully understand. It is very important that you clearly understand what this research entails and how you would be involved. Also, your participation is **entirely voluntary** and you are free to decline to participate. If you say no, this will not affect you negatively in any way whatsoever. You are also free to withdraw from the study at any point, even if you do agree to take part.

This study has been approved by the **Health Research Ethics Committee at Stellenbosch University** and will be conducted according to the ethical guidelines and principles of the international Declaration of Helsinki, South African Guidelines for Good Clinical Practice and the Medical Research Council (MRC) Ethical Guidelines for Research.

### **What is this research study all about?**

The study will be conducted at the Physiotherapy and FNB-3D Movement Analysis Laboratory at Stellenbosch University, Tygerberg Campus, Cape Town. A total of 30 participants will participate in the study. Data capturing will be conducted over 6 sessions in groups of 5 on a predetermined date at a time.

The study is aimed at analysing the lower limb movements of soccer and rugby players that have chronic groin injuries and comparing them to players that are uninjured. This will allow for a greater understanding as to the possible causing/ contributing factors of a groin injury.

Possible participants will be screened by two physiotherapists at their clubs and will then be invited to participate in the study at the FNB-3D Movement Analysis Laboratory. At the lab each participant will be booked for a particular time slot and then be allowed to familiarise themselves within the laboratory. The information sheet will be discussed again on the day of testing. Each participant will be asked to rate their current pain and their joint ranges of motion, weight, height and leg length will be measured before testing. Each participant will be asked to perform a maximum effort jump three times and to stand on one leg (pelican stance) at a time for 10 seconds and to repeat it three times. During this time the participants will be connected to external EMG electrodes to detect muscle activation patterns. The measurement will take approximately one hour.

### **Why have you been invited to participate?**

You have been identified by your rugby /soccer club as being a suitable participant for this study as either a case or control.

### **What will your responsibilities be?**

You will be asked to participate in activities as mentioned above at the motion laboratory on a predetermined date for one day only.

**Will you benefit from taking part in this research?**

By participating in this study research in the field of chronic adductor related pain will be better understood and the future prevention and management strategies could be improved.

**Are there in risks involved in your taking part in this research?**

There are no risks involved in this study.

**If you do not agree to take part, what alternatives do you have?**

The study is based on analyses of movement; if you do not wish to participate you are free to withdraw at any stage with no needed alternatives.

**Who will have access to your medical records?**

Only the investigating team and related supervisors will have access to the results obtained from the study. Each participant will be allocated with a number thereby ensuring confidentiality. Consent will be sought for the publication of results and the use of photographs taken during the study and the identity of the participants will remain anonymous.

**What will happen in the unlikely event of some form of injury occurring as a direct result of your taking part in this research study?**

There are no anticipated risks for participating in this study; each participant is however participating at his own risk.

**Will you be paid to take part in this study and are there any costs involved?**

You will not be remunerated for participating in the study, however your transport and meal costs will be covered for each study visit. There will be no costs involved for you, if you do participate.

**Is there anything else that you should know or do?**

You can contact the Health Research Ethics Committee at 021-938 9207 if you have any concerns or complaints that have not been adequately addressed by your researchers.

You will receive a copy of this information and the consent form for your own records.

### **Declaration by participant**

By signing below, I ..... agree to take part in a research study entitled: The kinematic and kinetic differences in athletes with chronic adductor related groin pain.

I declare that:

- I have read or had read to me this information and the consent form and it is written in a language with which I am fluent and comfortable.
- I have had a chance to ask questions and all my questions have been adequately answered.
- I understand that taking part in this study is **voluntary** and I have not been pressurised to take part.
- I may choose to leave the study at any time and will not be penalised or prejudiced in any way.
- I may be asked to leave the study before it has finished, if the study researcher feels it is in my best interests, or if I do not follow the study plan, as agreed to.

Signed at (*place*) ..... on (*date*) ..... 2014.

.....  
**Signature of participant**

.....  
**Signature of witness**



### Declaration by investigator

I (*name*) ..... declare that:

- I explained the information in this document to .....
- I encouraged him/her to ask questions and took adequate time to answer them.
- I am satisfied that he/she adequately understands all aspects of the research, as discussed above
- I did/did not use an interpreter. (*If an interpreter is used then the interpreter must sign the declaration below.*)

Signed at (*place*) ..... on (*date*) ..... 2014.

.....  
**Signature of investigator**

.....  
**Signature of witness**

## Declaration by interpreter

I (*name*) ..... declare that:

- I assisted the investigator (*name*) ..... to explain the information in this document to (*name of participant*) ..... using the language medium of Afrikaans/Xhosa.
- We encouraged him/her to ask questions and took adequate time to answer them.
- I conveyed a factually correct version of what was related to me.
- I am satisfied that the participant fully understands the content of this informed consent document and has had all his/her question satisfactorily answered.

Signed at (*place*) ..... on (*date*) ..... 2014.

.....  
**Signature of interpreter**

.....  
**Signature of witness**

**Table 15: Inclusion and exclusion criteria for cases**

Inclusion Criteria	Exclusion Criteria
<ul style="list-style-type: none"> <li>• Soccer and rugby players at a club level.</li> </ul>	<ul style="list-style-type: none"> <li>• Any orthopaedic surgical procedure of the lower quadrant and lumbar spine within the last 12 months</li> </ul>
<ul style="list-style-type: none"> <li>• Males between the ages of 18-55 years.</li> </ul>	<ul style="list-style-type: none"> <li>• Positive findings on previous imaging for bony lesions.</li> </ul>
<ul style="list-style-type: none"> <li>• Chronic groin pain of any intensity for more than 3 months.</li> </ul>	<ul style="list-style-type: none"> <li>• Any disease that has an influence on functional ability/movement e.g. Ankylosing Spondylitis, Scheuerman's disease, Rheumatoid Arthritis, Muscular Dystrophy and Paget's disease.</li> </ul>

<ul style="list-style-type: none"> <li>Groin pain during or after sporting activity.</li> </ul>	<ul style="list-style-type: none"> <li>History of spinal, lower limb or pelvis pathology other than groin injury.</li> </ul>
<ul style="list-style-type: none"> <li>Pain located at the proximal insertion of the adductor muscles on the pubic bone.</li> </ul>	<ul style="list-style-type: none"> <li>Symptoms of prostatitis or urinary tract infection.</li> </ul>
<ul style="list-style-type: none"> <li>Positive Adductor squeeze test with a sphygmomanometer (Delahunt et al 2011).</li> </ul>	<ul style="list-style-type: none"> <li>Clinical suspicion of nerve entrapment syndrome.</li> </ul>
<ul style="list-style-type: none"> <li>Participating in sport or physical training despite the groin injury.</li> </ul>	<ul style="list-style-type: none"> <li>Palpable inguinal or femoral hernia.</li> </ul>
<ul style="list-style-type: none"> <li>Good general health.</li> </ul>	

**Table 16: Inclusion and exclusion criteria for controls**

Inclusion Criteria	Exclusion Criteria
<ul style="list-style-type: none"> <li>Soccer&amp; Rugby players at a club level.</li> </ul>	<ul style="list-style-type: none"> <li>Any orthopaedic surgical procedure of the lower quadrant and lumbar spine within the last 12 months</li> </ul>
<ul style="list-style-type: none"> <li>Males between the ages of 18-55 years of age</li> </ul>	<ul style="list-style-type: none"> <li>Any positive findings on previous imaging for bony lesions</li> </ul>
<ul style="list-style-type: none"> <li>No history of groin pain</li> </ul>	<ul style="list-style-type: none"> <li>Any disease that has an influence on functional ability/movement e.g. Ankylosing Spondylitis, Scheuerman's disease, Rheumatoid Arthritis, Muscular Dystrophy and Paget's disease.</li> </ul>
<ul style="list-style-type: none"> <li>Negative Adductor squeeze test with a sphygmomanometer (Delahunt et al 2011)</li> </ul>	<ul style="list-style-type: none"> <li>History of spinal, lower limb or pelvis pathology other than groin injury.</li> </ul>
<ul style="list-style-type: none"> <li>Participating in sport or do a form of physical training</li> </ul>	
<ul style="list-style-type: none"> <li>Good general health</li> </ul>	

## Appendix H: Reflective marker placement

### Placement of the pelvis markers:

- Left ASIS/Right ASIS – directly over the anterior superior iliac spines
- Left PSIS/Right PSIS – directly over the posterior superior iliac spines

### Placement of knee markers:

- Left knee/Right knee – lateral epicondyle of the femur
- Left thigh/Right thigh - lower lateral 1/3 surface of the thigh, just below the swing of the hand
- Place the marker in a line from the greater trochanter and knee marker

### Placements of the tibia markers:

- Left tibia/Right tibia – lower lateral 1/3 of the tibia to determine the alignment of the ankle flexion axis. The marker is placed in a line joining the knee and the ankle markers
- A wand mounted marker may be used

### Placement of the ankle markers:

- Left ankle/Right ankle - lateral malleolus along an imaginary line that passes through the transmalleolar axis
- LMMAL/RMMAL – medial malleolus of the ankle (only used during the Oxford correction static subject calibration)
- The tibial marker should lie in the plane that contains the knee and ankle joint centres and the ankle flexion/extension axis.

### Placement of the foot markers:

- LTOE/RTOE - second metatarsal head, on the mid-foot side of the equinus break between fore-foot and mid-foot
- LHEE/RHEE - Place on the calcaneus at the same height above the plantar surface of the foot as the toe marker